NASA TN D-914

TECHNICAL NOTE

D-914

CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES

By E. W. Leyhe and R. R. Howell

Langley Research Center
Langley Air Force Base, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON January 1962

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-914

CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES

L
1
3
9
6

By E. W. Leyhe and R. R. Howell

SUMMARY

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8, and 0.7 for pressures varying between 10^{-4} and 8×10^{2} atmospheres and temperatures from 200° K to 3,000° K.

INTRODUCTION

The determination of the equilibrium composition and the corresponding thermodynamic, transport, and flow properties for a gaseous chemical reaction is necessary for certain problems in thermodynamics. Typical examples of such problems are (1) the expansion of combustion gases through a nozzle to obtain thrust as in the case of turbojet and ram-jet engines and (2) the utilization of combustion gases as the test medium in a wind tunnel for simulating combined heating and loading such as that obtained in hypersonic flight. In the latter case, the combustion generally takes place under very high pressure in order to achieve the desired velocity for simulation. Consequently, it is desirable to know the properties of such gases over ranges of pressures much greater than those for which information is presently available. (See refs. 1 and 2.)

In the present paper, procedures whereby computations of the composition, thermodynamic, transport, and flow properties for the products of combustion of two hydrocarbon fuels burning in air are presented.

Ethylene C_2H_4 and methane CH_4 are the two fuels considered. The properties of the combustion products are defined for a range of pressures between 10^{-4} and 8×10^2 atmospheres and for a range of temperatures between 200° K and 3,000° K. The properties have been computed for fuel-air equivalence ratios of 1.0, 0.9, 0.8, and 0.7. For these computations it is assumed that the combustion takes place at constant pressure, that the combustion efficiency is 100 percent, and that the gas is in chemical equilibrium.

SYMBOLS

A	cross-sectional area, sq ft
a	sonic velocity, ft/sec
B_1	proportion by volume of $C_{n_1}H_{m_1}$ in total fuel
B_2	proportion by volume of $C_{n_2}H_{n_2}$ in total fuel
B_3	proportion by volume of $C_{n_3}H_{m_3}$ in total fuel
B_4	proportion by volume of H_2O possibly mixed in fuel
C_nH_m	hydrocarbon fuel containing n atoms of carbon to m atoms of hydrogen
c_p	specific heat at constant pressure, Btu/lb-°R
D_1	ratio by volume of N_2 to O_2 in air
D_2	ratio by volume of Ar to O_2 in air
D_3	ratio by volume of CO_2 to O_2 in air
D_4	ratio by volume of H_2O to O_2 in air
E	moles of O_2 available for combustion
E_1	excess of moles of O_2 above that needed for stoichiometric case
F	ratio by volume of fuel to air

f	ratio by weight of fuel to air
g_c	gravitational conversion factor, $32.174 \frac{\text{lb-mass}}{\text{lb-force}} \frac{\text{ft}}{\text{sec}^2}$
H	total enthalpy, sensible plus chemical, Btu/lb
h	sensible enthalpy, Btu/lb
J	mechanical equivalent of heat
K	thermal conductivity, Btu/ft-sec-$^\circ$R
K_1 to K_7	chemical equilibrium constants based on partial pressures
k	Boltzmann's constant (gas constant for one molecule)
L_1, L_2, L_3, L_4	defined by equations (4), (5), (6), and (7), respectively
M	molecular weight, lb/lb-mole
m_1, m_2, m_3	number of atoms of hydrogen in fuels $C_{n_1}H_{m_1}$, $C_{n_2}H_{m_2}$, and $C_{n_3}H_{m_3}$, respectively
N_{Ma}	Mach number
N_{Pr}	Prandtl number
n	number of moles
n_i, n_j	number of moles of specie
n_1, n_2, n_3	number of atoms of carbon in fuels $C_{n_1}H_{m_1}$, $C_{n_2}H_{m_2}$, and $C_{n_3}H_{m_3}$, respectively
p	pressure, atm
p_i, p_j	partial pressure, atm
Q	heat of formation, Btu/lb
q	dynamic pressure, atm

R	universal gas constant, 1.98588 Btu/lb-mol-$^{\circ}$R
R_{eq}	equivalence ratio, equals f/f_s and F/F_s
R_{sp}	specific gas constant, Btu/lb-$^{\circ}$R
r	radius from cone vertex, ft
s	entropy, Btu/lb-$^{\circ}$R
T	temperature, $^{\circ}$K or $^{\circ}$R as required
V	velocity, ft/sec
W	total weight of gas, lb
X	mole fraction
x	distance along center line measured from nozzle throat, ft
y	cross-sectional radius of nozzle measured from center line, ft

$$\alpha = \left(\frac{\partial \log M}{\partial \log T}\right)_p$$

$$\beta = \left(\frac{\partial \log M}{\partial \log p}\right)_T$$

γ	isentropic exponent
Δ_h, δ_k	numerical step procedure constants
ϵ	Lennard-Jones force constant
ϵ_1	arbitrary criterion of accuracy for L_1/L_2
ϵ_2	arbitrary criterion of accuracy for p
θ	flow angle, deg
μ	viscosity, slugs/ft-sec
μ_i	viscosity of ith specie
ρ	density, slugs/ft^3

σ	collision diameter of molecule, angstroms
ϕ	defined by equation (43)
ψ	stream function
Ω	collision integral $\left(\text{called } \Omega^{(2,2)*} \text{ in ref. 15}\right)$

Subscripts:

c	calculated value
F	flame temperature
i	post-combustion specie
j	precombustion specie
L	lower limit
h,k,m,n	numerical indices in block diagram
l	post-combustion specie, dummy index
o	reference temperature, 0° K
p	constant pressure
r	reference temperature, 300° K
S	stoichiometric
s	constant entropy
T	constant temperature
t	stagnation or total
U	upper limit
w	wall condition

Superscript:

*	throat

For convenience, parentheses will be used when referring to specific species. For example, p_i for partial pressure of CO is

written $p(CO)$, n_1 for number of moles of CO_2, $n(CO_2)$, μ_1 for viscosity of H_2O, $\mu(H_2O)$.

PROCEDURE

The procedure for the computation of the gas properties of the combustion product is sufficiently general to include any combination of three hydrocarbon fuels together with an equivalence ratio R_{eq} which is less than or equal to one. The term "stoichiometric" refers to the condition of $R_{eq} = 1$.

L1396

In order to determine the gas properties of the combustion product, real gas effects, which may be considerable at the extreme conditions of high pressures and low temperatures, are omitted and the product gas is considered to be a calorically perfect gas with variable molecular weight. The equations employed for the calculations make use of the following assumptions: (1) the ideal gas equation of state is valid; (2) the properties of the species are functions of the temperature only; (3) the process is adiabatic; (4) the precombustion and post-combustion pressures are equal; (5) the gas is in chemical equilibrium; and (6) there is no phase change.

The development of the gas properties is divided into three sections: the composition, the thermodynamic properties, and the transport properties. The units are listed with the symbols and consistency is maintained by including conversion factors where necessary. The one exception is temperature for which T denotes both Kelvin and Rankine temperatures. Kelvin temperatures are used in the text; whereas both Kelvin and Rankine temperatures are used on the figures.

Gas Composition

The composition of the combustion product gas is obtained by using the equation for chemical reaction along with the equations expressing the chemical equilibrium constants. The equation for chemical reaction requires that the mass of each element in the initial constituents be equal to the mass of each element in the final constituents. As the mass of each element in the reaction is independent of dissociation, the mass of each element present can be obtained from the equation for chemical reaction in which there is no dissociation of the constituents. The final constituents are then allowed to dissociate and their relative proportions by volume are obtained from the equations expressing the chemical equilibrium constants.

In the chemical equation for combustion as used here, the initial constituents are the fuel and oxidizer. The fuel is assumed to consist

of an arbitrary mixture of three hydrocarbon fuels with possible water vapor present while the oxidizer, air, is assumed to consist of oxygen, nitrogen, argon, carbon dioxide, and water vapor. The choice of an equivalence ratio indicates the proportion of fuel to oxidizer while the constituents of each are left arbitrary.

The chemical equation for the burning of the fuel mixture in air when there is no dissociation is

$$B_1\left(C_{n_1}H_{m_1}\right) + B_2\left(C_{n_2}H_{m_2}\right) + B_3\left(C_{n_3}H_{m_3}\right) + E\left(O_2\right) + D_1E\left(N_2\right) + D_2E(Ar)$$
$$+ D_3E\left(CO_2\right) + \left(B_4 + D_4E\right)\left(H_2O\right) \longrightarrow \left(B_1n_1 + B_2n_2 + B_3n_3 + D_3E\right)\left(CO_2\right)$$
$$+ \left[\frac{1}{2}\left(B_1m_1 + B_2m_2 + B_3m_3\right) + B_4 + D_4E\right]\left(H_2O\right) + D_1E\left(N_2\right) + D_2E\ (Ar) + E_1\left(O_2\right) \tag{1}$$

where

$$E_1 = \frac{1 - R_{eq}}{R_{eq}}\left[B_1n_1 + B_2n_2 + B_3n_3 + \frac{1}{4}\left(B_1m_1 + B_2m_2 + B_3m_3\right)\right] \tag{2}$$

and

$$E = B_1n_1 + B_2n_2 + B_3n_3 + \frac{1}{4}\left(B_1m_1 + B_2m_2 + B_3m_3\right) + E_1 \tag{3}$$

The equations for conservation of mass for each element are obtained from equation (1). The masses are transformed into moles and the equations are expressed as ratios of two particular elements in their standard molecular state.

$$L_1 = \frac{n\left(O_2\right)}{n(C)} = \frac{E + D_3E + \frac{1}{2}\left(B_4 + D_4E\right)}{B_1n_1 + B_2n_2 + B_3n_3 + D_3E} \tag{4}$$

$$L_2 = \frac{n\left(N_2\right)}{n(C)} = \frac{D_1E}{B_1n_1 + B_2n_2 + B_3n_3 + D_3E} \tag{5}$$

$$L_3 = \frac{n(H_2)}{n(C)} = \frac{\frac{1}{2}\left(B_1m_1 + B_2m_2 + B_3m_3\right) + B_4 + D_4E}{B_1n_1 + B_2n_2 + B_3n_3 + D_3E} \tag{6}$$

$$L_4 = \frac{n(Ar)}{n(N_2)} = \frac{D_2}{D_1} \tag{7}$$

The constants L_1, L_2, L_3, and L_4 are therefore known quantities determined from the input values.

The constituents of the dissociated combustion product gas are next substituted into equations (4) to (7) in place of the input values and are now expressed in terms of partial pressures in order to utilize the equations for the chemical equilibrium constants. The definition of partial pressure leads to the relation:

$$\frac{p}{n} = \frac{p_i}{n_i} = \frac{p_i + p_j}{n_i + n_j} = . . . \tag{8}$$

where

$$n = \sum_i n_i \tag{9}$$

and

$$p = \sum_i p_i \tag{10}$$

By restricting the constituents of the dissociated combustion product gas to the species N_2, O_2, H_2, CO_2, H_2O, CO, OH, NO, O, H, N, and Ar, equations (4) to (7) can be rewritten as:

$$\frac{L_1}{L_2} = \frac{p(O_2) + p(CO_2) + \frac{1}{2}\left[p(H_2O) + p(CO) + p(NO) + p(OH) + p(O)\right]}{p(N_2) + \frac{1}{2}\left[p(NO) + p(N)\right]} \tag{11}$$

$$\frac{L_3}{L_2} = \frac{p(H_2O) + p(H_2) + \frac{1}{2}\left[p(OH) + p(H)\right]}{p(N_2) + \frac{1}{2}\left[p(NO) + p(N)\right]} \tag{12}$$

$$L_2 = \frac{p(N_2) + \frac{1}{2}\left[p(NO) + p(N)\right]}{p(CO_2) + p(CO)} \tag{13}$$

$$L_4 = \frac{D_2}{D_1} = \frac{p(Ar)}{p(N_2) + \frac{1}{2}\left[p(NO) + p(N)\right]} \tag{14}$$

Independent equations for the chemical equilibrium constants, which are functions of temperature, and their values were obtained from reference 3. These equations are:

$$K_1 = \frac{p(CO)p(H_2O)}{p(CO_2)p(H_2)} \tag{15}$$

$$K_2 = \frac{p(NO)p(H_2)}{p^{1/2}(N_2)p(H_2O)} \tag{16}$$

$$K_3 = \frac{p^2(H_2)p(O_2)}{p^2(H_2O)} \tag{17}$$

$$K_4 = \frac{p(H_2)p(O)}{p(H_2O)} \tag{18}$$

$$K_5 = \frac{p(H)}{p^{1/2}(H_2)} \tag{19}$$

$$K_6 = \frac{p^{1/2}(H_2)p(OH)}{p(H_2O)} \tag{20}$$

$$K_7 = \frac{p^2(N)}{p(N_2)} \tag{21}$$

Equations (10) to (21) represent 12 unknowns in 12 equations. The
unknowns are the partial pressures of the 12 species previously listed. L
The 12 equations are nonlinear and must be solved by a numerical step 1
procedure. As a result, it was found to be more convenient to put 3
equations (12) and (13) into the following form by substituting equa- 9
tions (15) to (21) into equations (12) and (13). 6

$$p(H_2O) = \frac{\frac{L_3}{L_2}\left[p(N_2) + \frac{1}{2}\sqrt{K_7 p(N_2)}\right] - p(H_2) - \frac{1}{2}K_5\sqrt{p(H_2)}}{1 + \frac{K_6}{2\sqrt{p(H_2)}} - \frac{L_3}{L_2}\frac{K_2}{2}\frac{\sqrt{p(N_2)}}{p(H_2)}} \tag{22}$$

$$p(CO) = \frac{K_1}{L_2}\,\frac{p(H_2)\left\{p(N_2) + \frac{1}{2}\left[p(NO) + p(N)\right]\right\}}{\left[p(H_2O) + K_1 p(H_2)\right]} \tag{23}$$

The equations are now solved as follows: For a particular reacting mixture select the temperature and pressure for the combustion products, and then assume values for $p(N_2)$ and $p(H_2)$. Solve the equations in the following order:

(a) equation (22) for $p(H_2O)$

(b) equation (16) for $p(NO)$

(c) equation (21) for $p(N)$

(d) equation (23) for $p(CO)$

(e) equation (15) for $p(CO_2)$

(f) equation (17) for $p(O_2)$

(g) equation (18) for $p(O)$

(h) equation (19) for $p(H)$

(i) equation (20) for $p(OH)$

(j) equation (14) for $p(Ar)$

(k) equation (11) for L_1/L_2

(l) equation (10) for p

This procedure follows that of appendix B of reference 4, which is for specific fuel and air compositions.

As the calculated value of L_1/L_2 is, in general, different from the known value, a new value of $p(H_2)$ is assumed and the equations are recalculated. This procedure is continued until the desired accuracy is obtained. The calculated total pressure is also, in general, different from the desired total pressure, in which case a new $p(N_2)$ must be assumed and the entire procedure retraced.

After a few trial calculations, it was noted that physically significant partial pressures were obtained only when both the numerator and denominator of equation (22) were positive. Compatibility with this restriction is obtained by confining $p(H_2)$ within limits which are established by setting both the numerator and denominator, respectively, equal to zero and by solving for $p(H_2)$. These limits are

$$p(H_2)_U = \left(\frac{1}{2}\left\{-\frac{K_5}{2} + \sqrt{\left(\frac{K_5}{2}\right)^2 + 4\frac{L_3}{L_2}\left[p(N_2) + \frac{1}{2}\sqrt{K_7 p(N_2)}\right]}\right\}\right)^2 \tag{24}$$

$$p(H_2)_L = \left\{\frac{1}{2}\left[-\frac{K_6}{2} + \sqrt{\left(\frac{K_6}{2}\right)^2 + 2\frac{L_3}{L_2}K_2\sqrt{p(N_2)}}\right]\right\}^2 \tag{25}$$

In order to provide an ordered sequence for the selection of the assumed values of $p(N_2)$ and $p(H_2)$, a numerical step procedure was devised. This procedure is shown in the block diagram in figure 1.

The number of moles of each specie is computed from the equation

$$n_i = \frac{n(CO_2) + n(CO)}{p(CO_2) + p(CO)} p_i \tag{26}$$

which is obtained from equation (8). This form was chosen because the sum of the numbers of moles of CO_2 and CO is equal to the number of moles of carbon entering into the reaction. Therefore, equation (26) can be rewritten in terms of known quantities. Thus,

$$n_i = \frac{B_1 n_1 + B_2 n_2 + B_3 n_3 + D_3 E}{p(CO_2) + p(CO)} p_i \tag{27}$$

In order to complete the identification of the gas, the mole fraction and the molecular weight of the mixture are obtained from the equations

$$\left.\begin{aligned} X_i &= n_i/n \\ \sum_i X_i &= 1 \end{aligned}\right\} \tag{28}$$

L1396

and

$$M = \sum_i X_i M_i \tag{29}$$

The mole fractions of the species are shown in figures 2 and 3 as functions of temperature for the combustion products of C_2H_4-air and CH_4-air mixtures, respectively. Because of the preponderance of data, these figures were selected at the equivalence ratios of 1.0 and 0.8 for the pressures of 10^{-4}, 10^{-2}, and 10^{0} atmospheres in order to illustrate the pressure effects on dissociation. Figures 4 and 5 show curves of molecular weight against temperature for lines of constant entropy, which is calculated in the section on thermodynamic properties, for the combustion products of C_2H_4-air and CH_4-air mixtures, respectively, both presented for the equivalence ratios of 1.0, 0.9, 0.8, and 0.7.

Thermodynamic Properties

The thermodynamic properties of the product gas when dissociation is considered are calculated from the equations to follow. (See refs. 1, 5, 6, 7, and 8.) Data for the pure species were obtained from references 3, 7, 9, 10, and 11. (Note that conversion factors are included where necessary to maintain consistency in units.)

Enthalpy, entropy, and density.- Enthalpy is defined as (see, for example, refs. 1 and 2):

$$H = \sum_i \frac{X_i M_i}{M} \left[\left(h_i - h_{i,r} \right) + Q_{i,r} \right] \tag{30}$$

where

$$h_i - h_{i,r} = 1.8 \int_{T_r}^{T} c_{p,i} \, dT$$

and $Q_{i,r}$, the heat of formation of the pure specie, is referenced to $T_r = 300^\circ$ K. Values of $Q_{i,r}$ are presented in table I, along with references.

Entropy is defined as (see, for example, refs. 1 and 2):

$$s = \sum_i \frac{X_i M_i}{M} \left(\int_{T_r}^{T} c_{p,i} \frac{dT}{T} + s_{i,r} - \frac{R}{M_i} \log_e p - \frac{R}{M_i} \log_e X_i \right) \tag{31}$$

where $s_{i,r}$ is the reference value of the specie entropy at $T_r = 300^\circ$ K and $p = 1$ atmosphere. Values of $s_{i,r}$ are also presented in table I with references.

The density may be expressed as

$$\rho = \frac{2116.8}{1.8} \frac{pM}{g_c JRT} = 1176 \frac{pM}{g_c JRT} \tag{32}$$

The three thermodynamic properties, enthalpy, entropy, and density, have been combined to form Mollier charts which are presented in figures 6 and 7 for the combustion products of C_2H_4-air and CH_4-air mixtures, respectively, for the equivalence ratios of 1.0, 0.9, 0.8, and 0.7. These Mollier charts are plotted with enthalpy, in the form $H - H_o$, as the ordinate, pressure as the abscissa, and for lines of constant entropy, density and temperature.

Specific heat at constant pressure.- The equation for specific heat is obtained from equation (30) by taking the derivative of H with respect to T with p held constant. By rewriting X_i/M as n_i/W where W is the weight of the gas

$$\left(\frac{\partial H}{\partial T}\right)_p = \sum_i \left\{ \frac{n_i M_i}{W}\left(\frac{\partial h_i}{\partial T}\right)_p + \frac{M_i}{W}\left[\left(h_i - h_{i,r}\right) + Q_{i,r}\right]\left(\frac{\partial n_i}{\partial T}\right)_p \right\} \tag{33}$$

or

$$c_p = \sum_i \left\{ \frac{X_i M_i}{M} c_{p,i} + \frac{1}{1.8}\frac{M_i}{M}\frac{\left[\left(h_i - h_{i,r}\right) + Q_{i,r}\right]}{n}\left(\frac{\partial n_i}{\partial T}\right)_p \right\} \tag{34}$$

The equations that express the specific heats of the species as functions of temperature are listed in table I, together with their references. Unfortunately, no values or equations for the specific heats of OH and NO had been found at the time of the programing. As a result, equations were written for these specific heats based on equations of similar compounds. Any inaccuracies introduced by these equations are felt to be small as the percentages of these species in the product gas are very low. These equations are also listed in table I. (Since the programing, values of these specific heats have been found (ref. 12) and the values compare favorably with those used in this report.)

L-1396

The specific heats for the combustion products of C_2H_4-air and CH_4-air mixtures are shown in figures 8 and 9, respectively, again for the equivalence ratios of 1.0, 0.9, 0.8, and 0.7. In these figures, the specific heat is plotted against temperature for lines of constant pressure.

Isentropic exponent.- The exponent (ref. 1) used to describe an isentropic change in state of a dissociating gas is no longer defined as the ratio of specific heats as for the case of an ideal gas. The definition is taken from the sonic velocity equation:

$$\gamma = \frac{\rho}{p}\left(\frac{\partial p}{\partial \rho}\right)_s = \left(\frac{\partial \log p}{\partial \log \rho}\right)_s \tag{35}$$

By using the basic thermodynamic relations (see ref. 6)

$$\left(\frac{\partial p}{\partial T}\right)_s = -\frac{g_c J c_p}{1176\frac{T}{\rho^2}\left(\frac{\partial \rho}{\partial T}\right)_p} \tag{36}$$

and

$$\left(\frac{\partial \rho}{\partial T}\right)_s = -\frac{\left(\frac{\partial \rho}{\partial p}\right)_T}{\left(\frac{\partial \rho}{\partial T}\right)_p}\left[\frac{\rho^2 g_c J c_p}{1176T} - \frac{\left(\frac{\partial \rho}{\partial T}\right)_p^2}{\left(\frac{\partial \rho}{\partial p}\right)_T}\right] \tag{37}$$

together with equation (32) and by defining

$$\alpha = \left(\frac{\partial \log M}{\partial \log T}\right)_p \tag{38}$$

and

$$\beta = \left(\frac{\partial \log M}{\partial \log p}\right)_T \tag{39}$$

equation (35) may be rewritten as

$$\gamma = \frac{c_p}{c_p(1 + \beta) - \frac{R}{M}(1 - \alpha)^2} \tag{40}$$

The isentropic exponents for the combustion products of C_2H_4-air and CH_4-air mixtures for the equivalence ratios of 1.0, 0.9, 0.8, and 0.7 are shown in figures 10 and 11, respectively. In these figures, the isentropic exponent is plotted against temperature for lines of constant entropy.

Specific gas constant.- The specific gas constant is defined as

$$R_{sp} = \frac{R}{M} \tag{41}$$

The specific gas constants were computed and tabulated but no figures were prepared as the values can be determined from the values of M given in the figures.

Flame temperature.- The flame temperature at a given pressure (ref. 7), which is fixed for a given fuel and oxidizer, equivalence ratio, and initial temperature of the precombustion species, is defined as the temperature at which

$$nMH = \sum n_iM_i\left[\left(h_i - h_{i,r}\right) + Q_{i,r}\right] = \sum n_jM_j\left[\left(h_j - h_{j,r}\right) + Q_{j,r}\right] \tag{42}$$

where the right-hand side refers to the precombustion species. The left-hand side refers to the combustion gas mixture. In order to obtain the flame temperature, the left-hand side of the equation is plotted from the data for a few temperatures, at constant pressure, against temperature, and the flame temperature is picked off the curve at the value equal to the right-hand side of the equation.

The flame temperature is shown in figure 12 as a function of equivalence ratio for the combustion of C_2H_4-air and CH_4-air mixtures with the

initial temperatures of the precombustion gas species chosen at 300° K. The flame temperature is plotted for lines of constant pressure of 1, 10, and 100 atmospheres to illustrate the effects of pressure.

Transport Properties

Because available data for the transport properties is extremely limited and in order to maintain as simple a procedure as possible, general equations are again used.

Viscosity.- From references 9, 13, and 14 the viscosities for all species except H_2O are represented by the equation:

L 1396

$$\mu_i = \frac{0.055749\sqrt{M_i T}}{\sigma^2 \Omega} \times 10^{-6} \tag{43}$$

where σ is the collision diameter of the molecule and Ω is the collision integral. Values of Ω were obtained from reference 15 where Ω is tabulated as a function of kT/ϵ. The symbol k represents the Boltzmann's constant and ϵ, the Lennard-Jones force constant. Values of σ and ϵ/k for the species were obtained from references 14 and 15 and are reproduced in table II. The values of σ and ϵ/k for the specie N were not found at the time of programing. However, the lack of these values should have little effect inasmuch as the percentage of N in the product gas is small.

The viscosity of the remaining specie H_2O is represented by the equations (see ref. 16)

$$\mu\left(H_2O\right) = \frac{0.053549\sqrt{T}}{1 + \frac{1371}{T} \times 10^{-\frac{37.4}{T}}} \times 10^{-6} \qquad (T \leqq 1300^\circ\ K) \tag{44}$$

$$\mu\left(H_2O\right) = \frac{0.031286\sqrt{T}}{1 + \frac{24.51 \times 10^4}{T^2}} \times 10^{-6} \qquad (T > 1300^\circ\ K) \tag{45}$$

For the gas mixture, reference 15 gives the equation

$$\mu = \sum_i \frac{\mu_i}{\sum_l \frac{X_l}{X_i} \phi_{i,l}} \tag{46}$$

where

$$\phi_{i,l} = \frac{\left[1 + \left(\frac{\mu_i}{\mu_l}\right)^{1/2}\left(\frac{M_l}{M_i}\right)^{1/4}\right]^2}{2\sqrt{2}\left(1 + \frac{M_i}{M_l}\right)^{1/2}} \tag{47}$$

The viscosity of the combustion products of C_2H_4-air and CH_4-air mixtures for the equivalence ratios of 1.0, 0.9, 0.8, and 0.7 are shown in figures 13 and 14, respectively. In these figures, the viscosity is plotted against temperature for lines of constant pressure.

Thermal conductivity.- From reference 14, an approximate relation for thermal conductivity of gaseous mixtures is the Eucken equation

$$K = g_c\left(c_p + \frac{5}{4}R_{sp}\right)\mu \tag{48}$$

The thermal conductivity is plotted against temperature for lines of constant pressure in figures 15 and 16 for the combustion products of C_2H_4-air and CH_4-air mixtures, respectively, and the equivalence ratios of 1.0, 0.9, 0.8, and 0.7.

Prandtl number.- A useful parameter in heat-transfer studies is the Prandtl number which is presented in this section on transport properties because the equation requires the values of the viscosity and thermal conductivity. This equation is

$$N_{Pr} = g_c \frac{c_p\mu}{K} \tag{49}$$

The Prandtl number is plotted against temperature for lines of constant pressure in figures 17 and 18 for the combustion products of C_2H_4-air and CH_4-air mixtures, respectively, with the equivalence ratios of 1.0, 0.9, 0.8, and 0.7.

RESULTS AND DISCUSSION

The preceding equations have been programed for the IBM 704 electronic data processing machine at the Langley Research Center. The required experimental data that are listed in tables I and II together with the data that related Ω to kT/ϵ have been stored in the program in proper order for the computation of the equations. In addition,

curve-fitting subroutines have been incorporated into the program in order to obtain the partial derivatives α, β, and $(\partial n_i/\partial T)_p$. The present arrangement covers a range of pressures from 0.0001 atmosphere to 800 atmospheres in steps denoted by the relation $p = 2^n \times 10^m$ where $n = 0, 1, 2, 3$ and m is zero or any positive or negative integer. The temperature range is from 200° K to 3,000° K in intervals of 100° K. The composition of air was taken as 0.7809 mole of N_2, 0.2089 mole of O_2, 0.0093 mole of Ar, and 0.0003 mole of CO_2 per mole of air.

The output of the IBM 704 is in the form of two tables, one of which tabulates X_i, n, and M against T and the other tabulates the thermodynamic and transport properties against T, both at a constant pressure for a given fuel and equivalence ratio. Examples of the tabulation are presented in tables III(a) and III(b). The accuracy of the data listed can be no more than four significant figures when based on the input data. However, the five to seven significant figures shown were retained as representative of the original printout. In addition to the tabular form, the data were also stored on magnetic tapes in an ordered sequence in order to utilize machine plotting. The plotting machines are programed to plot c_p, γ, μ, K, and N_{Pr} against T for lines of constant pressure.

Because the chemical equilibrium constants obtained from reference 3 were listed for every 100° K, the gas composition was also calculated and tabulated for every 100° K. Later, when the thermodynamic and transport properties were included in the program, it was desired to have these values in units of the English gravitational system for engineering use. Thus c_p, for example, is in BTU/lb-°R while tabulated against °K. In addition, the figures obtained from machine plotting were originally to be engineering work plots only with the abscissa in units of °R. However, because of the large amount of plotting to be done for this paper, it was decided to retain these plots and incorporate double temperature scales on the figures.

The product gas composition and the thermodynamic and transport properties of the combustion products of air with the hydrocarbon fuels ethylene C_2H_4 and methane CH_4 have been calculated for the equivalence ratios of 1.0, 0.9, 0.8, and 0.7. Because the tabular form is inconvenient to use for wind-tunnel or rocket work and also because of its bulkiness, the data have been reduced to a series of charts which are shown in figures 2 to 18. Regions in which comparison can be made between the present paper and reference 1 show agreement, in general, to within better than 1 percent.

CONCLUSION

A calculation procedure is presented from which the composition, thermodynamic properties and transport properties of a dissociated combustion product gas may be obtained when fuel consisting of a mixed hydrocarbon compound is burned in air. Calculations were made for the respective hydrocarbon fuels methane and ethylene and results are presented at the equivalence ratios of 1.0, 0.9, 0.8, and 0.7 for pressures varying between 10^{-4} and 8×10^{2} atmospheres and temperatures from 200° K to $3,000^{\circ}$ K.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., September 27, 1961.

APPENDIX A

CALCULATION OF FLOW CHARACTERISTICS AND SUPERSONIC NOZZLE ORDINATES FOR CALORICALLY PERFECT GASES WITH VARIABLE MOLECULAR WEIGHT

Mollier charts for gases are generally difficult to read accurately and are laborious to use, especially if they are to be used to compute nozzle ordinates and to determine flow properties along streamlines. In the following sections, equations to be used for the calculation of nozzle ordinates and flow properties are listed with explanations where necessary.

Flow Characteristics

Equations for flow properties with specific heat as a function of temperature and no dissociation have been developed in reference 17. These equations are here extended to include dissociation as a function of temperature only, that is, $\beta = 0$, together with the assumption of chemical equilibrium during expansion. On the Mollier charts (figs. 5 and 6), the condition $\beta = 0$ is restricted to the regions in which the constant-temperature lines are approximately parallel to the ordinates. Furthermore, it can be seen from these charts that, for any pair of stagnation pressures and temperatures in these regions, the flow properties during an expansion along a line of constant entropy will also lie in these regions.

The basic relations for the development of the flow properties along an isentrope are Bernoulli's equation and equations (32), (36), (37), and (40) of the text. By solving for the partial derivatives of the right-hand side of equations (36) and (37) of the text and by writing α in terms of γ, c_p, and R_{sp}, the following equations are obtained:

$$\frac{p}{p_t} = \exp \int_{T_t}^{T} \left[\frac{c_p \gamma}{R_{sp}(\gamma - 1)} \right]^{1/2} \frac{dT}{T} \qquad \text{(A1)}$$

$$\frac{\rho}{\rho_t} = \exp \int_{T_t}^{T} \left[\frac{c_p}{R_{sp}\gamma(\gamma - 1)} \right]^{1/2} \frac{dT}{T} \qquad \text{(A2)}$$

$$a = \left(1.8\gamma g_c J R_{sp} T\right)^{1/2} \tag{A3}$$

$$V = \left[3.6 g_c J \int_T^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT\right]^{1/2} \tag{A4}$$

L
1
3
9
6

$$N_{Ma} = \left[\frac{2 \int_T^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT}{\gamma R_{sp} T}\right]^{1/2} \tag{A5}$$

$$\frac{q}{p_t} = \frac{1}{R_{sp} T} \frac{p}{p_t} \int_T^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT \tag{A6}$$

$$T^* = \frac{2}{\gamma^* R_{sp}^*} \int_{T^*}^{T_t} \left(\frac{c_p R_{sp} \gamma}{\gamma - 1}\right)^{1/2} dT \tag{A7}$$

$$\frac{A}{A^*} = \frac{1}{N_{Ma}} \left(\frac{\gamma^* R_{sp} T}{\gamma R_{sp}^* T^*}\right)^{1/2} \exp \int_T^{T^*} \left[\frac{c_p \gamma}{R_{sp}(\gamma - 1)}\right]^{1/2} \frac{dT}{T} \tag{A8}$$

In equation (A7), T^* is not an explicit function as the integral also contains T^* as the lower limit. Furthermore, the equation is not amenable to the process of direct iteration, as the results diverge in an oscillatory manner. The scheme used here for the solution is to reduce successively the value of the lower limit by a constant decrement, say 5 K°, from a value known to be greater than the actual solution. Each time a value for the lower limit is chosen, the equation is calculated and the difference between the lower limit and the calculated value of T^* is noted. The process is continued until this difference changes sign. The calculated value of T^* is then within 5 K° of the actual value. If greater accuracy is desired, a smaller decrement is used. A good starting value for the lower limit is $T^* = \frac{2}{\gamma_t + 1} T_t$.

In order to solve these equations, a stagnation temperature is specified, together with the temperatures for which the equations are to be solved. Furthermore, tables of R_{sp}, c_p, and γ against T, such as are presented in this paper, must be available. The values of R_{sp}, c_p, and γ can be chosen at any pressure compatible with the assumption $\beta = 0$.

Flow properties of C_2H_4-air and CH_4-air combustion products at the equivalence ratios of 1.0 and 0.7 and for stagnation temperatures approximately that of the respective flame temperatures are presented in tables IV and V, respectively. The flow properties for these gases were computed on the IBM 704 electronic computer for temperatures at intervals of 5 K° from 200° K to 500° K and at 25 K° intervals from 500° K up to the stagnation temperature. The representative values of R_{sp}, c_p, and γ against T were chosen at the pressure of 40 atmospheres.

L 1 3 9 6

Supersonic Nozzles

A calorically perfect gas with variable molecular weight also requires modifications in the equations by which the wall coordinates and the distribution of flow properties are calculated for supersonic nozzles. These modifications are discussed here for the truncated conical nozzle and the contoured nozzle, again subject to the condition $\beta = 0$.

The truncated conical nozzle wall coordinates are completely specified once a cone angle and a throat diameter are chosen. Any radial line from the cone vertex through the nozzle is a streamline along which the flow properties are functions of the radius only. By combining the radial flow equations and the equations of continuity, motion, and state, the radius is written as a function of the temperatures. Thus,

$$\left(\frac{r}{r^*}\right) = \left\{\frac{R_{sp}T}{R_{sp}^*T^*}\left[\frac{\displaystyle\int_{T^*}^{T_t}\left(\frac{c_pR_{sp}\gamma}{\gamma - 1}\right)^{1/2}dT}{\displaystyle\int_{T}^{T_t}\left(\frac{c_pR_{sp}\gamma}{\gamma - 1}\right)^{1/2}dT}\right]^{1/2}\exp\left[\int_{T}^{T^*}\left(\frac{c_p\gamma}{R_{sp}\gamma - 1}\right)^{1/2}dT\right]\right\}^{1/2} \tag{A9}$$

where r^* is the radius from the vertex to the sonic line. The ratio r/r^* may be converted to x and y coordinates with $x = 0$ at the throat by the relations

$$\frac{x}{y^*} = \frac{r}{r^*}\frac{\cos\theta}{\sin\theta_w} - \frac{\cos\theta_w}{\sin\theta_w} \tag{A10}$$

and

$$\frac{y}{y^*} = \frac{r \sin \theta}{r^* \sin \theta_w} \tag{A11}$$

where θ_w is the wall angle and y^* is the throat radius from the center line. By using the same input data in equation (A9) that is used for equations (A1) to (A8), the distribution of the flow properties in the truncated conical nozzle is obtained.

L
1
3
9
6

The contoured nozzle wall and streamlines are designed by the usual method of characteristic networks. (See ref. 18.) The only modification to the characteristic method is that, once the velocity is found at a point, the Mach number is interpolated from data tabulated from equations (A1) to (A8) in order to determine the Mach angle. Further details are available in reference 19.

The stream function to be used in conjunction with the characteristic network system is developed from the equation of continuity across a Mach line and is made nondimensional by dividing through by the mass flow at the throat. Thus

$$d\psi = 2\left(\frac{\gamma R_{sp}^* T^*}{\gamma^* R_{sp} T}\right)^{1/2} \exp\left\{\int_{T^*}^{T}\left[\frac{c_p \gamma}{R_{sp}(\gamma - 1)}\right]^{1/2}\frac{dT}{T}\right\}\left(\frac{y}{y^*}\right)\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{1/2}\frac{dx}{y^*} \tag{A12}$$

In order to evaluate ψ and the corresponding flow properties, the velocity is obtained from the characteristic network equations, the properties are interpolated from the tables and substituted into equation (A12). The integration is along a Mach line and $\psi = 1$ at the nozzle wall.

Other flow regions which use radial flow or characteristic network equations incorporate these same modifications.

REFERENCES

1. Anon.: Properties of Combustion Gases/System: C_nH_{2n}-Air. Vol. I - Thermodynamic Properties. McGraw-Hill Book Co., Inc., c.1955. Vol. II - Chemical Composition of Equilibrium Mixtures. Gen. Elec. Co., c.1955.

2. Huff, Vearl N., and Calvert, Clyde S.: Charts for the Computation of Equilibrium Composition of Chemical Reactions in the Carbon-Hydrogen-Oxygen-Nitrogen System at Temperatures From 2000° to 5000° K. NACA TN 1653, 1948.

3. Martinez, J. S., and Elverum, G. W., Jr.: A Method of Calculating the Performance of Liquid-Propellant Systems Containing the Species C, H, O, N, F, and One Other Halogen - With Tables of Required Thermochemical Properties to 6000° K. Memo. No. 20-121 (Contract No. DA-04-495-Ord 18), Jet Propulsion Lab., C.I.T., Dec. 6, 1955.

4. Hershey, R. L., Eberhardt, J. E., and Hottel, H. C.: Thermodynamic Properties of the Working Fluid in Internal-Combustion Engines. SAE Jour., vol. 39, no. 4, Oct. 1936, pp. 409-424.

5. Taylor, Hugh S.: Elementary Physical Chemistry. D. Van Nostrand Co., Inc., 1927.

6. Zemansky, Mark W.: Heat and Thermodynamics. McGraw-Hill Book Co., Inc., 1943.

7. Glasstone, Samuel: Textbook of Physical Chemistry. Second ed., D. Van Nostrand Co., Inc., c.1946.

8. Slater, J. C.: Introduction to Chemical Physics. First ed., McGraw-Hill Book Co., Inc., 1939.

9. Hilsenrath, Joseph, Beckett, Charles W., et al.: Tables of Thermal Properties of Gases. NBS Cir. 564, U.S. Dept. Commerce, 1955.

10. Faires, Virgil Moring: Applied Thermodynamics. The MacMillan Co., 1938.

11. Perry, John H., ed.: Chemical Engineers' Handbook. Third ed., McGraw-Hill Book Co., Inc., 1950.

12. Huff, Vearl N., Gordon, Sanford, and Morrell, Virginia E.: General Method and Thermodynamic Tables for Computation of Equilibrium Composition and Temperature of Chemical Reactions. NACA Rep. 1037, 1951. (Supersedes NACA TN 2113 by Huff and Morrell and NACA TN 2161 by Huff and Gordon.)

13. Liley, P. E.: Survey of Recent Work on the Viscosity, Thermal Conductivity and Diffusion of Gases and Gas Mixtures. Thermodynamics and Transport Properties of Gases, Liquids, and Solids. McGraw-Hill Book Co., Inc., c.1959.

L
1
3
9
6

14. Gordon, Sanford, and McBride, Bonnie, J.: Theoretical Performance of Liquid Hydrogen With Liquid Oxygen as a Rocket Propellant. NASA MEMO 5-21-59E, 1959.

15. Reid, Robert C., and Sherwood, Thomas K.: The Properties of Gases and Liquids. McGraw-Hill Book Co., Inc., 1958.

16. Kestin, J., and Moszynski, J. R.: Review of Available Experimental Data on the Viscosity of Steam. Thermodynamic and Transport Properties of Gases, Liquids, and Solids. McGraw-Hill Book Co., Inc., c.1959.

17. Geissler, Ernest D., and Reisig, Gerhard: Calculations for a Supersonic Nozzle With Specific Heats Dependent on Temperature. Rep. 65, Ord. Guided Missile Center, Redstone Arsenal (Huntsville, Ala.) Sept. 1950.

18. Ferri, Antonio: Elements of Aerodynamics of Supersonic Flows. The MacMillan Co., 1949.

19. Guentert, Eleanor Costilow, and Neumann, Harvey E.: Design of Axisymmetric Exhaust Nozzles by Method of Characteristics Incorporating a Variable Isentropic Exponent. NASA TR R-33, 1959.

TABLE I.- HEAT OF FORMATION AND ENTROPY REFERENCE VALUES

AND SPECIFIC HEAT EQUATIONS

Specie	$Q_{i,r}$, Btu/lb (a)	$s_{i,r}$, Btu/lb-°R (b)	$c_{p,i}$, Btu/lb-°R (c)	References (d)
N_2	0	1.63391	$c_p = 0.2481$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 0.338 - \frac{68.78}{T} + \frac{1.28 \times 10^4}{T^2}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9 10
O_2	0	1.53201	$c_p = 0.2171$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 0.36 - \frac{4.006}{T^{1/2}} + \frac{26.56}{T}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9 10
H_2	0	15.49105	$c_p = 2.463 + 0.00325T$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 2.857 + \frac{5.161}{10^4}T + \frac{7.394}{T^{1/2}}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9 10
H_2O	-5,771.29	2.50465	$c_p = 0.4409$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 1.102 - \frac{24.67}{T^{1/2}} + \frac{231}{T}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9 10
CO_2	-3,844.19	1.16091	$c_p = 0.1579 + 0.000145T$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 0.368 - \frac{82.44}{T} + \frac{0.988 \times 10^4}{T^2}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9 10
CO	-1,696.29	1.68612	$c_p = 0.2481$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 0.338 - \frac{65.28}{T} + \frac{1.179 \times 10^4}{T^2}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9 10
NO	1,294.81	1.67792	$c_p = 0.2316$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 0.338 - \frac{97.5}{T} + \frac{1.97 \times 10^4}{T^2}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 3, 9 e
OH	1,064.30	2.58079	$c_p = 0.4119$ $(0^\circ\ K \leqq T < 300^\circ\ K)$ $c_p = 0.453 + \frac{29.77}{10^6}T - \frac{0.823}{T^{1/2}}$ $(300^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 3, 9 e
N	14,446.57	2.61429	$c_p = 0.3546$ $(0^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9
O	6,651.37	2.40473	$c_p = 0.3103$ $(0^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9
H	92,960.61	27.18804	$c_p = 4.9253$ $(0^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9
Ar	0	0.92607	$c_p = 0.1243$ $(0^\circ\ K \leqq T \leqq 3000^\circ\ K)$	3, 9, 9
CH_4	-2,007.50			3
C_2H_4	800.40			3

[a]Referenced to $T = 300^\circ$ K.

[b]Referenced to $T = 300^\circ$ K and $p = 1$ atmosphere.

[c]Equations contain conversion factors from °K to °R in constants.

[d]The references refer to $Q_{i,r}$, $s_{i,r}$, and $c_{p,i}$, respectively.

[e]See text.

L-1396

L-1396

TABLE II.- LENNARD-JONES FORCE CONSTANTS

[Taken from refs. 14 and 15]

Specie	σ, angstroms	ϵ/k, °K
N_2	3.681	91.5
O_2	3.433	113.0
H_2	2.968	33.3
H_2O	-----	-----
CO_2	3.996	190.0
CO	3.590	110.0
NO	3.470	119.0
OH	3.110	93.8
N	-----	-----
O	3.068	102.2
H	2.497	99.8
Ar	3.418	124.0

TABLE III.- SAMPLE PRINTOUT BY IBM 704 ELECTRONIC DATA PROCESSING MACHINE

(a) Product gas composition (example: C_2H_4; R_{eq} = 1; p = 0.0001 atm)

T	X_1 for -												n	M
	N_2	O_2	H_2	H_2O	CO_2	CO	NO	OH	N	O	H	Ar		
200	0.729927	0.000000	0.000013	0.130537	0.130830	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.008693	15.3198	28.9065
300	.729927	.000000	.000013	.130537	.130830	.000000	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9065
400	.729927	.000000	.000013	.130537	.130830	.000000	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9065
500	.729927	.000000	.000013	.130537	.130830	.000000	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9065
600	.729927	.000000	.000013	.130537	.130830	.000000	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9065
700	.729927	.000000	.000013	.130537	.130829	.000001	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9065
800	.729927	.000000	.000013	.130537	.130827	.000003	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9064
900	.729927	.000000	.000013	.130537	.130825	.000006	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9064
1,000	.729927	.000000	.000013	.130537	.130821	.000009	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9063
1,100	.729925	.000002	.000013	.130536	.130817	.000013	.000000	.000000	.000000	.000000	.000000	.008693	15.3198	28.9063
1,200	.729894	.000040	.000026	.130517	.130789	.000036	.000003	.000003	.000000	.000000	.000000	.008692	15.3205	28.9058
1,300	.729813	.000136	.000097	.130426	.130640	.000170	.000011	.000015	.000000	.000000	.000001	.008692	15.3221	28.9027
1,400	.729567	.000418	.000287	.130168	.130148	.000621	.000034	.000058	.000000	.000002	.000008	.008689	15.3270	28.8929
1,500	.728893	.001169	.000715	.129537	.128819	.001835	.000094	.000195	.000000	.000016	.000047	.008681	15.3406	28.8671
1,600	.727279	.002880	.001582	.128129	.125732	.004644	.000232	.000556	.000000	.000087	.000216	.008663	15.3732	28.8068
1,700	.723879	.006186	.003197	.125208	.119426	.010366	.000507	.001384	.000000	.000391	.000832	.008624	15.4424	28.6769
1,800	.717241	.011836	.005921	.119549	.108290	.020356	.000996	.003050	.000000	.001464	.002750	.008548	15.5800	28.4241
1,900	.705365	.019970	.010085	.109277	.091359	.035227	.001765	.005950	.000000	.004636	.007956	.008411	15.8335	27.9693
2,000	.685808	.029361	.015552	.092157	.069708	.053467	.002812	.010161	.000000	.012550	.020240	.008184	16.2720	27.2155
2,100	.656567	.036950	.020784	.067185	.046950	.071081	.003900	.014768	.000000	.029122	.044850	.007842	16.9811	26.0790
2,200	.618557	.038466	.022293	.038157	.027464	.083853	.004996	.017301	.000001	.057562	.083955	.007396	18.0054	24.5954
2,300	.579978	.031672	.017563	.014981	.013938	.090505	.005450	.015306	.000003	.095621	.128045	.006940	19.1904	23.0760
2,400	.551811	.020148	.010145	.003983	.006266	.093103	.005168	.010108	.000009	.132708	.159948	.006602	20.1702	21.9555
2,500	.536470	.010401	.004903	.000834	.002615	.093936	.004391	.005464	.000023	.158797	.175751	.006415	20.7589	21.3329
2,600	.529406	.004816	.002268	.000164	.001072	.094137	.003511	.002718	.000056	.173097	.182428	.006326	21.0515	21.0360
2,700	.526321	.002178	.001067	.000034	.000450	.094144	.002751	.001341	.000128	.180061	.185241	.006285	21.1883	20.9005
2,800	.524952	.001004	.000522	.000007	.000198	.094111	.002153	.000677	.000273	.183359	.186478	.006266	21.2525	20.8371
2,900	.524208	.000480	.000266	.000002	.000091	.094069	.001702	.000354	.000556	.184989	.187027	.006256	21.2861	20.8042
3,000	.523578	.000239	.000141	.000000	.000044	.094019	.001361	.000192	.001080	.185846	.187248	.006250	21.3079	20.7831

TABLE III.- SAMPLE PRINTOUT BY IBM 704 ELECTRONIC DATA PROCESSING MACHINE - Concluded

(b) Thermodynamic and transport properties (example: C_2H_4; $R_{eq} = 1$; p = 0.0001 atm)

T	H	c_p	γ	s	$\log_{10} \rho$	R_{sp}	μ	K	N_{Pr}
200	-1,280.62	0.250110	1.37870	2.18783	-6.46662	0.068700	0.024290 × 10^{-5}	0.002625 × 10^{-3}	0.744408
300	-1,235.25	.255885	1.36702	2.28997	-6.64271	.068700	.034186	.003759	.748727
400	-1,189.40	.256397	1.36602	2.36325	-6.76765	.068700	.042904	.004724	.749102
500	-1,142.49	.265335	1.34938	2.42138	-6.86456	.068700	.050756	.005735	.755488
600	-1,093.84	.275122	1.33282	2.47063	-6.94374	.068700	.058067	.006743	.762116
700	-1,043.49	.284112	1.31893	2.51372	-7.01069	.068700	.064912	.007726	.767897
800	-991.63	.292023	1.30764	2.55219	-7.06868	.068700	.071386	.008678	.772756
900	-938.43	.298914	1.29843	2.58699	-7.11984	.068700	.077560	.009601	.776825
1,000	-884.07	.304860	1.29091	2.61880	-7.16559	.068701	.083201	.010458	.780221
1,100	-828.70	.310264	1.28441	2.64811	-7.20699	.068701	.088651	.011298	.783218
1,200	-772.28	.316773	1.27731	2.67538	-7.24478	.068702	.093986	.012174	.786720
1,300	-714.38	.327129	1.26750	2.70112	-7.27959	.068709	.099364	.013202	.792050
1,400	-653.91	.346830	1.25181	2.72601	-7.31192	.068732	.104371	.014530	.801464
1,500	-588.23	.387056	1.22690	2.75118	-7.34227	.068794	.109334	.016638	.818217
1,600	-512.05	.467697	1.19348	2.77846	-7.37121	.068938	.114294	.020365	.844418
1,700	-415.65	.616803	1.15950	2.81089	-7.39950	.069250	.119398	.027016	.876931
1,800	-283.53	.872576	1.12393	2.85278	-7.42817	.069866	.124951	.038585	.909020
1,900	-92.26	1.283897	1.10486	2.91014	-7.45866	.071002	.131341	.057998	.935342
2,000	190.29	1.902371	1.09418	2.99054	-7.49280	.072969	.140117	.089862	.954248
2,100	601.73	2.718765	1.08847	3.10189	-7.53252	.076149	.153530	.138983	.966174
2,200	1,159.22	3.405451	1.08863	3.24574	-7.57816	.080742	.172997	.195140	.971216
2,300	1,786.45	3.319712	1.09622	3.40045	-7.62515	.086058	.196554	.216726	.968613
2,400	2,311.70	2.419806	1.11081	3.52450	-7.66525	.090450	.218686	.178188	.955362
2,500	2,651.24	1.446793	1.13825	3.60141	-7.69548	.093090	.235559	.118439	.925559
2,600	2,851.37	.859179	1.18545	3.64498	-7.71860	.094404	.247571	.077826	.879240
2,700	2,978.25	.585151	1.24224	3.67156	-7.73779	.095016	.256706	.058120	.831274
2,800	3,071.96	.469533	1.28829	3.69049	-7.75491	.095305	.264281	.050105	.797624
2,900	3,152.20	.430505	1.31225	3.70613	-7.77083	.095456	.271097	.048028	.782986
3,000	3,228.28	.414239	1.31784	3.72046	-7.78600	.095553	.277590	.047289	.776194

TABLE IV.- FLOW PROPERTIES OF C_2H_4-AIR COMBUSTION PRODUCTS

[Letter E denotes that number to left of E is to be multiplied by 10 to the power indicated by number to right; for example, 0.10479973E 01 = 0.10479923 × 10^1]

(a) R_{eq} = 1.0; T_t = 2,500° K; T^* = 2,271.7° K

N_{Ma}	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.	0.09999999E 01	0.09999999E 01	0.	0.	0.	0.09999999E 01
0.32736685E-00	0.93807644E 00	0.98999999E 00	0.32593057E-00	0.60286310E-01	0.19238102E 01	0.94811858E 00
0.46345924E-00	0.88014272E 00	0.98000000E 00	0.45939400E-00	0.11358106E-p0	0.14392466E 01	0.89914436E 00
0.56822821E 00	0.82592688E 00	0.97000000E 00	0.56076721E 00	0.16053364E-00	0.12430036E 01	0.85289384E 00
0.65691037E 00	0.77516310E 00	0.95999999E 00	0.64539229E 00	0.20174956E-00	0.11383269E 01	0.80920615E 00
0.73537856E 00	0.72760946E 00	0.95000000E 00	0.71923582E 00	0.23777048E-00	0.10763889E 01	0.76790848E 00
0.80665433E 00	0.68304368E 00	0.94000000E 00	0.78537094E 00	0.26908748E-00	0.10385734E 01	0.72884968E 00
0.87251703E 00	0.64126431E 00	0.93000000E 00	0.84562713E 00	0.29614120E-00	0.10160987E 01	0.69188698E 00
0.93419082E 00	0.60207519E 00	0.91999999E 00	0.90121395E 00	0.31934687E-00	0.10042020E 01	0.65690260E 00
0.99248334E 00	0.56529780E 00	0.91000000E 00	0.95297407E 00	0.33906811E-00	0.10001151E 01	0.62376198E 00
0.10479973E 01	0.53076809E 00	0.90000000E 00	0.10015238E 01	0.35563666E-00	0.10020989E 01	0.59234958E 00
0.11011724E 01	0.49833364E-00	0.88999999E 00	0.10473332E 01	0.36935019E-00	0.10090261E 01	0.56255206E 00
0.11524265E 01	0.46785571E-00	0.88000000E 00	0.10907659E 01	0.38048995E-00	0.10201035E 01	0.53428652E 00
0.12020222E 01	0.43920550E-00	0.87000000E 00	0.11321139E 01	0.38929826E-00	0.10348169E 01	0.50745364E 00
0.12501965E 01	0.41226359E-00	0.86000000E 00	0.11716156E 01	0.39599886E-00	0.10528029E 01	0.48196744E-00
0.12971216E 01	0.38692091E-00	0.84999999E 00	0.12094674E 01	0.40079228E-00	0.10738179E 01	0.45774665E-00
0.13430405E 01	0.36307272E-00	0.84000000E 00	0.12458385E 01	0.40387121E-00	0.10976773E 01	0.43472391E-00
0.13880705E 01	0.34062304E-00	0.83000000E 00	0.12808726E 01	0.40539898E-00	0.11242921E 01	0.41282395E-00
0.14323402E 01	0.31948331E-00	0.81999999E 00	0.13146929E 01	0.40552726E-00	0.11536130E 01	0.39198145E-00
0.14759425E 01	0.29957108E-00	0.80999999E 00	0.13474075E 01	0.40439056E-00	0.11856426E 01	0.37213219E-00
0.15190428E 01	0.28081086E-00	0.80000000E 00	0.13791087E 01	0.40212390E-00	0.12203764E 01	0.35322952E-00
0.15617047E 01	0.26313236E-00	0.79000000E 00	0.14098790E 01	0.39883688E-00	0.12578892E 01	0.33521679E-00
0.16040120E 01	0.24647022E-00	0.77999999E 00	0.14397913E 01	0.39463333E-00	0.12982599E 01	0.31804514E-00
0.16460560E 01	0.23076153E-00	0.77000000E 00	0.14689156E 01	0.38960502E-00	0.13416158E 01	0.30166502E-00
0.16878728E 01	0.21595311E-00	0.76000000E 00	0.14973044E 01	0.38384512E-00	0.13880655E 01	0.28604206E-00
0.17295370E 01	0.20199391E-00	0.75000000E 00	0.15250077E 01	0.37742203E-00	0.14377691E 01	0.27113700E-00
0.17711081E 01	0.18883570E-00	0.73999999E 00	0.15520714E 01	0.37043943E-00	0.14909064E 01	0.25691408E-00
0.18126487E 01	0.17643201E-00	0.73000000E 00	0.15785407E 01	0.36293128E-00	0.15477017E 01	0.24333633E-00
0.18542004E 01	0.16474260E-00	0.72000000E 00	0.16044494E 01	0.35497881E-00	0.16083460E 01	0.23037985E-00
0.18958154E 01	0.15372882E-00	0.70999999E 00	0.16298304E 01	0.34663723E-00	0.16731045E 01	0.21801408E-00
0.19375413E 01	0.14335397E-00	0.70000000E 00	0.16547143E 01	0.33796022E-00	0.17422613E 01	0.20621188E-00
0.19794584E 01	0.13358215E-00	0.69000000E 00	0.16791332E 01	0.32899519E-00	0.18161469E 01	0.19494559E-00
0.20215185E 01	0.12438293E-00	0.68000000E 00	0.17031082E 01	0.31979140E-00	0.18950965E 01	0.18419441E-00
0.20638002E 01	0.11572659E-00	0.66999999E 00	0.17266609E 01	0.31039269E-00	0.19794815E 01	0.17393681E-00
0.21063446E 01	0.10758465E-00	0.66000000E 00	0.17498121E 01	0.30083951E-00	0.20697241E 01	0.16415199E-00
0.21491639E 01	0.99930414E-01	0.65000000E 00	0.17725804E 01	0.29116864E-00	0.21662932E 01	0.15481991E-00
0.21923827E 01	0.92737798E-01	0.63999999E 00	0.17949851E 01	0.28141785E-00	0.22696824E 01	0.14592311E-00
0.22360081E 01	0.85982301E-01	0.63000000E 00	0.18170439E 01	0.27161682E-00	0.23804805E 01	0.13744216E-00
0.22800837E 01	0.79640776E-01	0.62000000E 00	0.18387730E 01	0.26179478E-00	0.24993269E 01	0.12935965E-00
0.23247463E 01	0.73689504E-01	0.61000000E 00	0.18601948E 01	0.25197414E-00	0.26269895E 01	0.12165592E-00
0.23697747E 01	0.68110442E-01	0.59999999E 00	0.18813138E 01	0.24218722E-00	0.27641774E 01	0.11432017E-00
0.24153155E 01	0.62885055E-01	0.59000000E 00	0.19021384E 01	0.23246022E-00	0.29117183E 01	0.10733925E-00
0.24614071E 01	0.57995133E-01	0.58000000E 00	0.19226775E 01	0.22281678E-00	0.30705377E 01	0.10069992E-00
0.25080931E 01	0.53423170E-01	0.56999999E 00	0.19429397E 01	0.21327879E-00	0.32416607E 01	0.94389387E-01
0.25554058E 01	0.49152444E-01	0.55999999E 00	0.19629330E 01	0.20386554E-00	0.34262382E 01	0.88394858E-01
0.26033926E 01	0.45166899E-01	0.55000000E 00	0.19826649E 01	0.19459559E-00	0.36255360E 01	0.82704373E-01
0.26520988E 01	0.41451133E-01	0.54000000E 00	0.20021427E 01	0.18548546E-00	0.38409713E 01	0.77306134E-01
0.27016095E 01	0.37990073E-01	0.52999999E 00	0.20213749E 01	0.17654859E-00	0.40741639E 01	0.72187940E-01
0.27518675E 01	0.34770074E-01	0.52000000E 00	0.20403653E 01	0.16780099E-00	0.43268249E 01	0.67339944E-01
0.28029677E 01	0.31777809E-01	0.51000000E 00	0.20591187E 01	0.15925495E-00	0.46009161E 01	0.62751529E-01
0.28549636E 01	0.29000416E-01	0.50000000E 00	0.20776397E 01	0.15092152E-00	0.48986337E 01	0.58412366E-01
0.29078805E 01	0.26425775E-01	0.48999999E-00	0.20959313E 01	0.14281133E-00	0.52224018E 01	0.54312859E-01
0.29618690E 01	0.24041731E-01	0.48000000E-00	0.21140003E 01	0.13493077E-00	0.55750653E 01	0.50442315E-01
0.30169586E 01	0.21836837E-01	0.47000000E-00	0.21318521E 01	0.12728626E-00	0.59597964E 01	0.46790913E-01
0.30792208E 01	0.19800227E-01	0.45999999E-00	0.21494917E 01	0.11988316E-00	0.63801880E 01	0.43349168E-01
0.31307571E 01	0.17921441E-01	0.45000000E-00	0.21669249E 01	0.11272487E-00	0.68403763E 01	0.40107552E-01
0.31895775E 01	0.16190791E-01	0.44000000E-00	0.21841546E 01	0.10581640E-00	0.73449068E 01	0.37057862E-01
0.32497987E 01	0.14598962E-01	0.43000000E-00	0.22011843E 01	0.99160072E-01	0.78990614E 01	0.34191497E-01
0.33115141E 01	0.13137054E-01	0.41999999E-00	0.22180176E 01	0.92757532E-01	0.85088661E 01	0.31500203E-01
0.33749618E 01	0.11796261E-01	0.41000000E-00	0.22346620E 01	0.86607555E-01	0.91814651E 01	0.28975185E-01
0.34398497E 01	0.10569064E-01	0.40000000E-00	0.22511145E 01	0.80713009E-01	0.99245302E 01	0.26609854E-01
0.35064570E 01	0.94480173E-02	0.38999999E-00	0.22673745E 01	0.75074875E-01	0.10746934E 02	0.24397326E-01
0.35749036E 01	0.84259126E-02	0.38000000E-00	0.22834424E 01	0.69692446E-01	0.11658972E 02	0.22330564E-01
0.36453056E 01	0.74959301E-02	0.37000000E-00	0.22993175E 01	0.64564553E-01	0.12672454E 02	0.20402828E-01
0.37178510E 01	0.66514251E-02	0.36000000E-00	0.23150018E 01	0.59688063E-01	0.13801292E 02	0.18607111E-01
0.37926829E 01	0.58861328E-02	0.34999999E-00	0.23304965E 01	0.55059432E-01	0.15061653E 02	0.16936705E-01
0.38699785E 01	0.51941334E-02	0.34000000E-00	0.23458029E 01	0.50674579E-01	0.16472415E 02	0.15385133E-01
0.39500102E 01	0.45697734E-02	0.33000000E-00	0.23609231E 01	0.46528338E-01	0.18055946E 02	0.13945945E-01
0.40327711E 01	0.40078527E-02	0.31999999E-00	0.23758566E 01	0.42616274E-01	0.19838127E 02	0.12613312E-01

L-1396

TABLE IV.- FLOW PROPERTIES OF C_2H_4-AIR COMBUSTION PRODUCTS - Continued

(a) $R_{eq} = 1.0$; $T_t = 2,500^\circ$ K; $T^* = 2,271.7^\circ$ K - Concluded

M	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.41185953E 01	0.35034180E-02	0.30999999E-00	0.23906031E 01	0.38933063E-01	0.21849667E 02	0.11381454E-01
0.42077485E 01	0.30517855E-02	0.30000000E-00	0.24051629E 01	0.35472778E-01	0.24127106E 02	0.10244726E-01
0.43006079E 01	0.26485234E-02	0.29000000E-00	0.24195373E 01	0.32228792E-01	0.26714325E 02	0.91975791E-02
0.43972749E 01	0.22895365E-02	0.27999999E-00	0.24337253E 01	0.29194853E-01	0.29663417E 02	0.82348811E-02
0.44982252E 01	0.19709604E-02	0.27000000E-00	0.24477265E 01	0.26364144E-01	0.33037347E 02	0.73516026E-02
0.46038841E 01	0.16891710E-02	0.26000000E-00	0.24615409E 01	0.23729479E-01	0.36912612E 02	0.65428688E-02
0.47147499E 01	0.14407928E-02	0.25000000E-00	0.24751680E 01	0.21283583E-01	0.41382417E 02	0.58040281E-02
0.48313403E 01	0.12226563E-02	0.23999999E-00	0.24886087E 01	0.19018674E-01	0.46562073E 02	0.51305172E-02
0.49543142E 01	0.10318242E-02	0.23000000E-00	0.25018635E 01	0.16926962E-01	0.52594523E 02	0.45179969E-02
0.50844144E 01	0.86557692E-03	0.22000000E-00	0.25149332E 01	0.15000641E-01	0.59658528E 02	0.39623337E-02
0.52220196E 01	0.72147156E-03	0.20999999E-00	0.25278113E 01	0.13233148E-01	0.67973150E 02	0.34599355E-02
0.53695855E 01	0.59706429E-03	0.20000000E-00	0.25405090E 01	0.11614660E-01	0.77834146E 02	0.30064861E-02
0.54003257E 01	0.57435194E-03	0.19800000E-00	0.25430275E 01	0.11308083E-01	0.80023584E 02	0.29213326E-02
0.54314993E 01	0.55232409E-03	0.19599999E-00	0.25455391E 01	0.11007062E-01	0.82293260E 02	0.28379583E-02
0.54631180E 01	0.53096481E-03	0.19400000E-00	0.25480438E 01	0.10711536E-01	0.84645901E 02	0.27563357E-02
0.54951935E 01	0.51025844E-03	0.19199999E-00	0.25505418E 01	0.10421442E-01	0.87088446E 02	0.26764373E-02
0.55277379E 01	0.49018964E-03	0.19000000E-00	0.25530329E 01	0.10136717E-01	0.89622077E 02	0.25982363E-02
0.55607637E 01	0.47074345E-03	0.18799999E-00	0.25555173E 01	0.98573018E-02	0.92252189E 02	0.25217066E-02
0.55942840E 01	0.45190502E-03	0.18600000E-00	0.25579949E 01	0.95831339E-02	0.94983474E 02	0.24468218E-02
0.56283126E 01	0.43365987E-03	0.18399999E-00	0.25604659E 01	0.93141536E-02	0.97820873E 02	0.23735562E-02
0.56628635E 01	0.41599382E-03	0.18200000E-00	0.25629303E 01	0.90503016E-02	0.10076962E 03	0.23018849E-02
0.56979512E 01	0.39889286E-03	0.18000000E-00	0.25653880E 01	0.87915179E-02	0.10383532E 03	0.22317825E-02
0.57294741E 01	0.38239487E-03	0.17800000E-00	0.25678314E 01	0.85388437E-02	0.10700975E 03	0.21635162E-02
0.57657628E 01	0.36643971E-03	0.17600000E-00	0.25702670E 01	0.82912564E-02	0.11030973E 03	0.20968046E-02
0.58027212E 01	0.35100269E-03	0.17399999E-00	0.25726965E 01	0.80484512E-02	0.11374496E 03	0.20315584E-02
0.58403686E 01	0.33607018E-03	0.17200000E-00	0.25751202E 01	0.78103507E-02	0.11732293E 03	0.19677487E-02
0.58787247E 01	0.32162894E-03	0.16999999E-00	0.25775382E 01	0.75768800E-02	0.12105162E 03	0.19053479E-02
0.59178101E 01	0.30766615E-03	0.16800000E-00	0.25799508E 01	0.73479686E-02	0.12493960E 03	0.18443296E-02
0.59576462E 01	0.29416926E-03	0.16599999E-00	0.25823583E 01	0.71235452E-02	0.12899601E 03	0.17846675E-02
0.59982556E 01	0.28112617E-03	0.16400000E-00	0.25847607E 01	0.69035442E-02	0.13323067E 03	0.17263369E-02
0.60396615E 01	0.26852499E-03	0.16199999E-00	0.25871584E 01	0.66878991E-02	0.13765414E 03	0.16693132E-02
0.60818881E 01	0.25635427E-03	0.16000000E-00	0.25895514E 01	0.64765490E-02	0.14227773E 03	0.16135733E-02
0.61249609E 01	0.24460280E-03	0.15800000E-00	0.25919402E 01	0.62694331E-02	0.14711358E 03	0.15590946E-02
0.61689064E 01	0.23325963E-03	0.15600000E-00	0.25943247E 01	0.60664920E-02	0.15217479E 03	0.15058547E-02
0.62137523E 01	0.22231414E-03	0.15400000E-00	0.25967053E 01	0.58676701E-02	0.15747550E 03	0.14538328E-02
0.62595274E 01	0.21175601E-03	0.15200000E-00	0.25990821E 01	0.56729139E-02	0.16303089E 03	0.14030085E-02
0.63062620E 01	0.20157511E-03	0.15000000E-00	0.26014554E 01	0.54821692E-02	0.16885737E 03	0.13533613E-02
0.63539879E 01	0.19176164E-03	0.14799999E-00	0.26038254E 01	0.52953874E-02	0.17497268E 03	0.13048726E-02
0.64027381E 01	0.18230593E-03	0.14600000E-00	0.26061922E 01	0.51125178E-02	0.18139600E 03	0.12575234E-02
0.64525475E 01	0.17319866E-03	0.14399999E-00	0.26085561E 01	0.49335144E-02	0.18814810E 03	0.12112956E-02
0.65034524E 01	0.16443068E-03	0.14200000E-00	0.26109172E 01	0.47583314E-02	0.19525154E 03	0.11661720E-02
0.65554908E 01	0.15599305E-03	0.13999999E-00	0.26132757E 01	0.45869255E-02	0.20273075E 03	0.11221356E-02
0.66166152E 01	0.14783340E-03	0.13800000E-00	0.26156449E 01	0.44179932E-02	0.21067345E 03	0.10788513E-02
0.66709065E 01	0.13998353E-03	0.13600000E-00	0.26180142E 01	0.42526148E-02	0.21906451E 03	0.10365880E-02
0.67262927E 01	0.13244491E-03	0.13400000E-00	0.26203808E 01	0.40910360E-02	0.22792251E 03	0.99540222E-03
0.67828153E 01	0.12520978E-03	0.13200000E-00	0.26227447E 01	0.39332393E-02	0.23728032E 03	0.95528389E-03
0.68405183E 01	0.11827051E-03	0.13000000E-00	0.26251058E 01	0.37792075E-02	0.24717364E 03	0.91622309E-03
0.68994479E 01	0.11161944E-03	0.12800000E-00	0.26274639E 01	0.36289198E-02	0.25764128E 03	0.87820923E-03
0.69596530E 01	0.10524899E-03	0.12599999E-00	0.26298188E 01	0.34823552E-02	0.26872547E 03	0.84123149E-03
0.70211854E 01	0.99151604E-04	0.12400000E-00	0.26321706E 01	0.33394898E-02	0.28047233E 03	0.80527862E-03
0.70840997E 01	0.93319793E-04	0.12199999E-00	0.26345191E 01	0.32002994E-02	0.29293200E 03	0.77033928E-03
0.71484536E 01	0.87746107E-04	0.12000000E-00	0.26368641E 01	0.30647574E-02	0.30615949E 03	0.73640160E-03
0.72143087E 01	0.82423190E-04	0.11799999E-00	0.26392056E 01	0.29328366E-02	0.32021485E 03	0.70345371E-03
0.72817297E 01	0.77343708E-04	0.11600000E-00	0.26415434E 01	0.28045068E-02	0.33516400E 03	0.67148314E-03
0.73507857E 01	0.72500418E-04	0.11399999E-00	0.26438776E 01	0.26797379E-02	0.35107919E 03	0.64047734E-03
0.74215502E 01	0.67886163E-04	0.11200000E-00	0.26462077E 01	0.25584981E-02	0.36803994E 03	0.61042366E-03
0.74941006E 01	0.63493837E-04	0.11000000E-00	0.26485340E 01	0.24407537E-02	0.38613369E 03	0.58130893E-03
0.75685208E 01	0.59316413E-04	0.10800000E-00	0.26508561E 01	0.23264697E-02	0.40545700E 03	0.55311984E-03
0.76448988E 01	0.55346977E-04	0.10600000E-00	0.26531740E 01	0.22156109E-02	0.42611650E 03	0.52584307E-03
0.77233294E 01	0.51578673E-04	0.10399999E-00	0.26554876E 01	0.21081396E-02	0.44823005E 03	0.49946487E-03
0.78039133E 01	0.48004749E-04	0.10200000E-00	0.26577968E 01	0.20040178E-02	0.47192857E 03	0.47397140E-03
0.78867589E 01	0.44618533E-04	0.99999999E-01	0.26601015E 01	0.19032055E-02	0.49735741E 03	0.44934862E-03
0.79719816E 01	0.41413466E-04	0.97999999E-01	0.26624015E 01	0.18056626E-02	0.52467819E 03	0.42558236E-03
0.80597062E 01	0.38383070E-04	0.95999999E-01	0.26646969E 01	0.17113470E-02	0.55407149E 03	0.40265823E-03
0.81500654E 01	0.35520984E-04	0.93999999E-01	0.26669873E 01	0.16202164E-02	0.58573879E 03	0.38056185E-03
0.82432035E 01	0.32820942E-04	0.91999999E-01	0.26692729E 01	0.15322272E-02	0.61990607E 03	0.35927857E-03
0.83392750E 01	0.30276784E-04	0.90000000E-01	0.26715535E 01	0.14473347E-02	0.65682702E 03	0.33879372E-03
0.84384466E 01	0.27882452E-04	0.88000000E-01	0.26738289E 01	0.13654931E-02	0.69678721E 03	0.31909236E-03
0.85408992E 01	0.25632014E-04	0.85999999E-01	0.26760991E 01	0.12866566E-02	0.74010888E 03	0.30015971E-03
0.86468284E 01	0.23519637E-04	0.84000000E-01	0.26783639E 01	0.12107779E-02	0.78715663E 03	0.28198074E-03
0.87564465E 01	0.21539606E-04	0.81999999E-01	0.26806234E 01	0.11378093E-02	0.83834430E 03	0.26454041E-03
0.88699838E 01	0.19686317E-04	0.79999999E-01	0.26828773E 01	0.10677020E-02	0.89414262E 03	0.24782357E-03
0.89876920E 01	0.17954290E-04	0.77999999E-01	0.26851255E 01	0.10004072E-02	0.95508908E 03	0.23181511E-03

L-1396

TABLE IV.- FLOW PROPERTIES OF C_2H_4-AIR COMBUSTION PRODUCTS - Continued

(b) R_{eq} = 0.7; T_t = 1,900° K; T^* = 1,678.6° K

N_{Ma}	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.	0.09999999E 01	0.09999999E 01	0.	0.	0.	0.09999999E 01
0.32103197E-00	0.93756385E 00	0.98684210E 00	0.31904475E-00	0.60847906E-01	0.19433614E 01	0.95007965E 00
0.45647816E-00	0.87846262E 00	0.97368421E 00	0.45080835E-00	0.11536767E-00	0.14482895E 01	0.90223121E 00
0.56212743E 00	0.82255451E 00	0.96052631E 00	0.55163272E 00	0.16396639E-00	0.12469320E 01	0.85639162E 00
0.65273906E 00	0.76968094E 00	0.94736842E 00	0.63641495E 00	0.20705052E-00	0.11392306E 01	0.81248094E 00
0.73397953E 00	0.71969621E 00	0.93421052E 00	0.71092746E 00	0.24499799E-00	0.10754999E 01	0.77042356E 00
0.80875652E 00	0.67246319E 00	0.92105263E 00	0.77813253E 00	0.27816456E-00	0.10368104E 01	0.73015029E 00
0.87881908E 00	0.62784547E 00	0.90789473E 00	0.83979981E 00	0.30688909E-00	0.10142428E 01	0.69158810E 00
0.94524368E 00	0.58572642E 00	0.89473684E 00	0.89706730E 00	0.33148538E-00	0.10030168E 01	0.65468432E 00
0.10088265E 01	0.54599036E 00	0.88157894E 00	0.95072963E 00	0.35225284E-00	0.10003457E 01	0.61938124E 00
0.10701400E 01	0.50852493E 00	0.86842105E 00	0.10013672E 01	0.36947651E-00	0.10045097E 01	0.58562239E 00
0.11296164E 01	0.47322256E-00	0.85526315E 00	0.10494184E 01	0.38342629E-00	0.10144120E 01	0.55335285E 00
0.11876083E 01	0.43997917E-00	0.84210526E 00	0.10952246E 01	0.39435938E-00	0.10293395E 01	0.52252050E 00
0.12443887E 01	0.40869510E-00	0.82894737E 00	0.11390579E 01	0.40251783E-00	0.10488377E 01	0.49307289E-00
0.13001864E 01	0.37927479E-00	0.81578947E 00	0.11811385E 01	0.40813097E-00	0.10726275E 01	0.46495987E-00
0.13551935E 01	0.35162652E-00	0.80263157E 00	0.12216485E 01	0.41141569E-00	0.11005583E 01	0.43813291E-00
0.14095787E 01	0.32566249E-00	0.78947368E 00	0.12607399E 01	0.41257670E-00	0.11325788E 01	0.41254491E-00
0.14634860E 01	0.30129842E-00	0.77631579E 00	0.12985416E 01	0.41180756E-00	0.11687165E 01	0.38815048E-00
0.15170442E 01	0.27845355E-00	0.76315789E 00	0.13351638E 01	0.40929075E-00	0.12090667E 01	0.36490551E-00
0.15703958E 01	0.25704850E-00	0.75000000E 00	0.13707048E 01	0.40519713E-00	0.12537912E 01	0.34276467E-00
0.16235751E 01	0.23701212E-00	0.73684210E 00	0.14052428E 01	0.39969036E-00	0.13030927E 01	0.32169071E-00
0.16767050E 01	0.21827462E-00	0.72368421E 00	0.14388478E 01	0.39292419E-00	0.13572308E 01	0.30164536E-00
0.17298746E 01	0.20076850E-00	0.71052631E 00	0.14715822E 01	0.38504313E-00	0.14165203E 01	0.28259072E-00
0.17831714E 01	0.18442871E-00	0.69736842E 00	0.15035020E 01	0.37618276E-00	0.14813332E 01	0.26448953E-00
0.18366703E 01	0.16919324E-00	0.68421052E 00	0.15346561E 01	0.36647136E-00	0.15520963E 01	0.24730647E-00
0.18904532E 01	0.15500241E-00	0.67105263E 00	0.15650888E 01	0.35602830E-00	0.16293039E 01	0.23100647E-00
0.19445979E 01	0.14179894E-00	0.65789473E 00	0.15948398E 01	0.34496540E-00	0.17135200E 01	0.21555543E-00
0.19991845E 01	0.12952788E-00	0.64473684E 00	0.16239455E 01	0.33338702E-00	0.18053874E 01	0.20092008E-00
0.20542824E 01	0.11813670E-00	0.63157894E 00	0.16524385E 01	0.32139040E-00	0.19056365E 01	0.18706816E-00
0.21099733E 01	0.10757507E-00	0.61842105E 00	0.16803484E 01	0.30906600E-00	0.20150959E 01	0.17396832E-00
0.21663371E 01	0.97794816E-01	0.60526315E 00	0.17077024E 01	0.29649768E-00	0.21347083E 01	0.16159000E-00
0.22234931E 01	0.88749091E-01	0.59210526E 00	0.17345282E 01	0.28376132E-00	0.22655612E 01	0.14990222E-00
0.22814205E 01	0.80395085E-01	0.57894737E 00	0.17608450E 01	0.27093066E-00	0.24088548E 01	0.13887801E-00
0.23402480E 01	0.72691241E-01	0.56578947E 00	0.17866722E 01	0.25807291E-00	0.25659613E 01	0.12849027E-00
0.24000651E 01	0.65597609E-01	0.55263157E 00	0.18120282E 01	0.24524916E-00	0.27384517E 01	0.11871216E-00
0.24610034E 01	0.59075452E-01	0.53947368E 00	0.18369322E 01	0.23251336E-00	0.29281469E 01	0.10951642E-00
0.25230581E 01	0.53089195E-01	0.52631579E 00	0.18613966E 01	0.21991883E-00	0.31370696E 01	0.10087933E-00
0.25863764E 01	0.47604397E-01	0.51315789E 00	0.18854344E 01	0.20751228E-00	0.33675595E 01	0.92776620E-01
0.26510703E 01	0.42588033E-01	0.50000000E 00	0.19090580E 01	0.19533536E-00	0.36223123E 01	0.85184430E-01
0.27172640E 01	0.38008709E-01	0.48684210E-00	0.19322784E 01	0.18342571E-00	0.39044256E 01	0.78079743E-01
0.27850778E 01	0.33836244E-01	0.47368421E-00	0.19551076E 01	0.17181464E-00	0.42175296E 01	0.71439175E-01
0.28546604E 01	0.30042033E-01	0.46052631E-00	0.19775562E 01	0.16053054E-00	0.45658202E 01	0.65240549E-01
0.29261685E 01	0.26598955E-01	0.44736842E-00	0.19996343E 01	0.14959767E-00	0.49541983E 01	0.59462242E-01
0.29998310E 01	0.23481034E-01	0.43421052E-00	0.20213533E 01	0.13903499E-00	0.53884736E 01	0.54082557E-01
0.30756714E 01	0.20664395E-01	0.42105263E-00	0.20427193E 01	0.12886234E-00	0.58753040E 01	0.49082444E-01
0.31539644E 01	0.18126211E-01	0.40789473E-00	0.20637390E 01	0.11909416E-00	0.64226156E 01	0.44442504E-01
0.32349379E 01	0.15844818E-01	0.39473684E-00	0.20844191E 01	0.10974170E-00	0.70398116E 01	0.40143863E-01
0.33189549E 01	0.13799469E-01	0.38157894E-00	0.21047693E 01	0.10081137E-00	0.77382483E 01	0.36167465E-01
0.34059844E 01	0.11971378E-01	0.36842105E-00	0.21247913E 01	0.92311291E-01	0.85311806E 01	0.32496743E-01
0.34964735E 01	0.10342564E-01	0.35526315E-00	0.21444884E 01	0.84245771E-01	0.94345951E 01	0.29115101E-01
0.35907775E 01	0.88960221E-02	0.34210526E-00	0.21638644E 01	0.76615895E-01	0.10467882E 02	0.26006167E-01
0.36892678E 01	0.76158877E-02	0.32894737E-00	0.21829213E 01	0.69421338E-01	0.11654477E 02	0.23154446E-01
0.37925040E 01	0.64869642E-02	0.31578947E+00	0.22016657E 01	0.62656960E-01	0.13023560E 02	0.20543960E-01
0.39009852E 01	0.54951718E-02	0.30263157E-00	0.22201028E 01	0.56316541E-01	0.14611163E 02	0.18159646E-01
0.40153336E 01	0.46274301E-02	0.28947368E-00	0.22382376E 01	0.50392500E-01	0.16462203E 02	0.15987153E-01
0.41358662E 01	0.38719644E-02	0.27631579E-00	0.22560647E 01	0.44879864E-01	0.18631495E 02	0.14014126E-01
0.42646277E 01	0.32168598E-02	0.26315789E-00	0.22736029E 01	0.39761958E-01	0.21193103E 02	0.12225203E-01
0.42913955E 01	0.30969311E-02	0.26052631E-00	0.22770771E 01	0.38784502E-01	0.21760416E 02	0.11888316E-01
0.43185227E 01	0.29805115E-02	0.25789473E-00	0.22805403E 01	0.37822186E-01	0.22348008E 02	0.11558160E-01

L-1396

L-1396

TABLE IV.- FLOW PROPERTIES OF C_2H_4-AIR COMBUSTION PRODUCTS - Concluded

(b) $R_{eq} = 0.7$; $T_t = 1,900^\circ$ K; $T^* = 1,678.6^\circ$ K - Concluded

N_{Ma}	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.43460184E 01	0.28675220E-02	0.25526316E-00	0.22839926E 01	0.36874896E-01	0.22956812E 02	0.11234635E-01
0.43738929E 01	0.27578866E-02	0.25263157E-00	0.22874341E 01	0.35942540E-01	0.23587804E 02	0.10917649E-01
0.44021561E 01	0.26515297E-02	0.25000000E-00	0.22908649E 01	0.35025008E-01	0.24242027E 02	0.10607105E-01
0.44308187E 01	0.25483770E-02	0.24736842E-00	0.22942850E 01	0.34122194E-01	0.24920577E 02	0.10302907E-01
0.44598915E 01	0.24483560E-02	0.24473684E-00	0.22976945E 01	0.33233999E-01	0.25624616E 02	0.10004965E-01
0.44893861E 01	0.23513953E-02	0.24210526E-00	0.23010936E 01	0.32360318E-01	0.26355375E 02	0.97131883E-02
0.45193142E 01	0.22574246E-02	0.23947368E-00	0.23044822E 01	0.31501045E-01	0.27114155E 02	0.94274850E-02
0.45496880E 01	0.21663749E-02	0.23684210E-00	0.23078604E 01	0.30656078E-01	0.27902340E 02	0.91477672E-02
0.45772097E 01	0.20784484E-02	0.23421052E-00	0.23112179E 01	0.29828911E-01	0.28717801E 02	0.88750991E-02
0.46085690E 01	0.19933344E-02	0.23157895E-00	0.23145633E 01	0.29016300E-01	0.29564783E 02	0.86083811E-02
0.46404827E 01	0.19109076E-02	0.22894736E-00	0.23178992E 01	0.28217331E-01	0.30445724E 02	0.83472694E-02
0.46729672E 01	0.18310998E-02	0.22631579E-00	0.23212259E 01	0.27431829E-01	0.31362475E 02	0.80916584E-02
0.47060393E 01	0.17538452E-02	0.22368421E-00	0.23245436E 01	0.26659630E-01	0.32317016E 02	0.78414491E-02
0.47397161E 01	0.16790795E-02	0.22105262E-00	0.23278526E 01	0.25900573E-01	0.33311471E 02	0.75965426E-02
0.47740162E 01	0.16067405E-02	0.21842105E-00	0.23311534E 01	0.25154503E-01	0.34348106E 02	0.73568455E-02
0.48089585E 01	0.15367672E-02	0.21578947E-00	0.23344461E 01	0.24421275E-01	0.35429352E 02	0.71222665E-02
0.48445624E 01	0.14691004E-02	0.21315789E-00	0.23377311E 01	0.23700744E-01	0.36557818E 02	0.68927171E-02
0.48808486E 01	0.14036826E-02	0.21052631E-00	0.23410086E 01	0.22992774E-01	0.37736299E 02	0.66681127E-02
0.49178386E 01	0.13404577E-02	0.20789474E-00	0.23442791E 01	0.22297239E-01	0.38967804E 02	0.64483712E-02
0.49555549E 01	0.12793709E-02	0.20526315E-00	0.23475428E 01	0.21614007E-01	0.40255564E 02	0.62334124E-02
0.49940207E 01	0.12203688E-02	0.20263158E-00	0.23507998E 01	0.20942961E-01	0.41603055E 02	0.60231596E-02
0.50332603E 01	0.11633995E-02	0.20000000E-00	0.23540507E 01	0.20283986E-01	0.43014036E 02	0.58175389E-02
0.50732993E 01	0.11084121E-02	0.19736842E-00	0.23572955E 01	0.19636970E-01	0.44492545E 02	0.56164774E-02
0.51141644E 01	0.10553572E-02	0.19473684E-00	0.23605347E 01	0.19001807E-01	0.46042953E 02	0.54199057E-02
0.51558837E 01	0.10041862E-02	0.19210526E-00	0.23637684E 01	0.18378398E-01	0.47669981E 02	0.52277568E-02
0.51984863E 01	0.95485204E-03	0.18947368E-00	0.23669971E 01	0.17766644E-01	0.49378739E 02	0.50399654E-02
0.52420028E 01	0.90730853E-03	0.18684210E-00	0.23702209E 01	0.17166457E-01	0.51174764E 02	0.48564691E-02
0.52864656E 01	0.86151052E-03	0.18421052E-00	0.23734401E 01	0.16577746E-01	0.53064059E 02	0.46772063E-02
0.53382670E 01	0.81718349E-03	0.18157894E-00	0.23766723E 01	0.15996151E-01	0.55068278E 02	0.45008494E-02
0.53846329E 01	0.77449667E-03	0.17894737E-00	0.23799033E 01	0.15425373E-01	0.57183574E 02	0.43284722E-02
0.54319179E 01	0.73345955E-03	0.17631578E-00	0.23831299E 01	0.14866310E-01	0.59414465E 02	0.41603068E-02
0.54801569E 01	0.69403318E-03	0.17368421E-00	0.23863516E 01	0.14318963E-01	0.61768999E 02	0.39963204E-02
0.55293863E 01	0.65617874E-03	0.17105263E-00	0.23895684E 01	0.13783329E-01	0.64255902E 02	0.38364786E-02
0.55796447E 01	0.61985760E-03	0.16842105E-00	0.23927802E 01	0.13259403E-01	0.66884661E 02	0.36807469E-02
0.56309729E 01	0.58503125E-03	0.16578947E-00	0.23959868E 01	0.12747169E-01	0.69665590E 02	0.35290881E-02
0.56834139E 01	0.55166136E-03	0.16315789E-00	0.23991881E 01	0.12246609E-01	0.72609947E 02	0.33814648E-02
0.57370132E 01	0.51970974E-03	0.16052631E-00	0.24023840E 01	0.11757696E-01	0.75729977E 02	0.32378373E-02
0.57916191E 01	0.48913851E-03	0.15789473E-00	0.24055742E 01	0.11280401E-01	0.79039088E 02	0.30981654E-02
0.58478826E 01	0.45991000E-03	0.15526316E-00	0.24087588E 01	0.10814685E-01	0.82551912E 02	0.29624077E-02
0.59052579E 01	0.43198673E-03	0.15263157E-00	0.24119376E 01	0.10360505E-01	0.86284509E 02	0.28305212E-02
0.59640023E 01	0.40533159E-03	0.15000000E-00	0.24151103E 01	0.99178133E-02	0.90254474E 02	0.27024619E-02
0.60241771E 01	0.37990776E-03	0.14736842E-00	0.24182770E 01	0.94865571E-02	0.94481130E 02	0.25781853E-02
0.60858473E 01	0.35567872E-03	0.14473684E-00	0.24214374E 01	0.90666756E-02	0.98985783E 02	0.24576452E-02
0.61490820E 01	0.33260836E-03	0.14210526E-00	0.24245914E 01	0.86581068E-02	0.10379186E 03	0.23407950E-02
0.62139550E 01	0.31066081E-03	0.13947368E-00	0.24277390E 01	0.82607788E-02	0.10892528E 03	0.22275866E-02
0.62805448E 01	0.28980072E-03	0.13684210E-00	0.24308799E 01	0.78746186E-02	0.11441467E 03	0.21179714E-02
0.63489360E 01	0.26999301E-03	0.13421052E-00	0.24340142E 01	0.74995457E-02	0.12029176E 03	0.20118996E-02
0.64192183E 01	0.25120310E-03	0.13157894E-00	0.24371415E 01	0.71354751E-02	0.12659180E 03	0.19093211E-02
0.64914885E 01	0.23339684E-03	0.12894736E-00	0.24402620E 01	0.67823187E-02	0.13335398E 03	0.18101846E-02
0.65658496E 01	0.21654049E-03	0.12631579E-00	0.24433753E 01	0.64399816E-02	0.14062200E 03	0.17144383E-02
0.66424132E 01	0.20060081E-03	0.12368421E-00	0.24464814E 01	0.61083660E-02	0.14844466E 03	0.16220297E-02
0.67212985E 01	0.18554500E-03	0.12105263E-00	0.24495801E 01	0.57873685E-02	0.15687664E 03	0.15329056E-02
0.68026347E 01	0.17134076E-03	0.11842105E-00	0.24526714E 01	0.54768809E-02	0.16597925E 03	0.14470121E-02
0.68865609E 01	0.15795631E-03	0.11578947E-00	0.24557551E 01	0.51767931E-02	0.17582150E 03	0.13642950E-02
0.69732274E 01	0.14536034E-03	0.11315789E-00	0.24588311E 01	0.48869883E-02	0.18648124E 03	0.12846991E-02
0.70627972E 01	0.13352211E-03	0.11052631E-00	0.24618994E 01	0.46073467E-02	0.19804648E 03	0.12081695E-02
0.71554470E 01	0.12241139E-03	0.10789473E-00	0.24649598E 01	0.43377452E-02	0.21061704E 03	0.11346501E-02
0.72513688E 01	0.11199851E-03	0.10526315E-00	0.24680120E 01	0.40780564E-02	0.22430646E 03	0.10640848E-02
0.73507720E 01	0.10225433E-03	0.10263158E-00	0.24710563E 01	0.38281485E-02	0.23924430E 03	0.99641693E-03

TABLE V.- FLOW PROPERTIES OF CH_4-AIR COMBUSTION PRODUCTS

[Letter E denotes that number to left of E is to be multiplied by 10 to the power indicated by number to right; for example, 0.10479973E 01 = 0.10479923×10^{1}]

(a) $R_{eq} = 1.0$; $T_t = 2,200^\circ$ K; $T^* = 1,969.1^\circ$ K

N_{Ma}	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.	0.09999999E 01	0.09999999E 01	0.	0.	0.	0.09999999E 01
0.32031149E-00	0.93925402E 00	0.98863636E 00	0.31872664E-00	0.59206981E-01	0.19553246E 01	0.95025802E 00
0.45421194E-00	0.88206812E 00	0.97727273E 00	0.44969694E-00	0.11199609E-00	0.14584464E 01	0.90295967E 00
0.55786669E 00	0.82821533E 00	0.96590909E 00	0.54951788E 00	0.15890032E-00	0.12561180E 01	0.85795892E 00
0.64608930E 00	0.77749030E 00	0.95454545E 00	0.63312786E 00	0.20040445E-00	0.11475126E 01	0.81513561E 00
0.72460299E 00	0.72970086E 00	0.94318181E 00	0.70633470E 00	0.23695260E-00	0.10827357E 01	0.77436506E 00
0.79635032E 00	0.68466784E 00	0.93181818E 00	0.77212833E 00	0.26895290E-00	0.10427655E 01	0.73553377E 00
0.86305806E 00	0.64223028E 00	0.92045454E 00	0.83228403E 00	0.29677486E-00	0.10186332E 01	0.69853690E 00
0.92593609E 00	0.60222399E 00	0.90909091E 00	0.88798021E 00	0.32077403E-00	0.10054894E 01	0.66328166E 00
0.98577103E 00	0.56450021E 00	0.89772727E 00	0.94003578E 00	0.34126489E-00	0.10005210E 01	0.62966304E 00
0.10431547E 01	0.52892207E 00	0.88636363E 00	0.98904860E 00	0.35853730E-00	0.10019746E 01	0.59759153E 00
0.10985625E 01	0.49535378E-00	0.87500000E 00	0.10354847E 01	0.37285687E-00	0.10087301E 01	0.56697001E 00
0.11522983E 01	0.46369030E-00	0.86363636E 00	0.10796801E 01	0.38447113E-00	0.10200109E 01	0.53774809E 00
0.12046519E 01	0.43382770E-00	0.85227273E 00	0.11219089E 01	0.39360128E-00	0.10353199E 01	0.50985491E 00
0.12558533E 01	0.40566651E-00	0.84090909E 00	0.11623970E 01	0.40045600E-00	0.10543217E 01	0.48322695E-00
0.13061035E 01	0.37911163E-00	0.82954545E 00	0.12013339E 01	0.40522820E-00	0.10768060E 01	0.45780189E-00
0.13555486E 01	0.35407785E-00	0.81818181E 00	0.12388725E 01	0.40809858E-00	0.11026431E 01	0.43352806E-00
0.14043356E 01	0.33048386E-00	0.80681818E 00	0.12751444E 01	0.40923349E-00	0.11317790E 01	0.41035315E-00
0.14525887E 01	0.30825257E-00	0.79545454E 00	0.13102630E 01	0.40878821E-00	0.11642160E 01	0.38822793E-00
0.15004285E 01	0.28730991E-00	0.78409091E 00	0.13443288E 01	0.40690456E-00	0.12000143E 01	0.36710209E-00
0.15479290E 01	0.26758938E-00	0.77272727E 00	0.13774243E 01	0.40372410E-00	0.12392431E 01	0.34694011E-00
0.15951881E 01	0.24902714E-00	0.76136363E 00	0.14096231E 01	0.39936978E-00	0.12820390E 01	0.32769856E-00
0.16422873E 01	0.23156247E-00	0.75000000E 00	0.14409909E 01	0.39395892E-00	0.13285679E 01	0.30933840E-00
0.16893190E 01	0.21513584E-00	0.73863636E 00	0.14715900E 01	0.38759912E-00	0.13790420E 01	0.29181959E-00
0.17363139E 01	0.19969575E-00	0.72727273E 00	0.15014676E 01	0.38039570E-00	0.14336853E 01	0.27511165E-00
0.17833509E 01	0.18519186E-00	0.71590909E 00	0.15306679E 01	0.37244516E-00	0.14927673E 01	0.25918251E-00
0.18304919E 01	0.17157576E-00	0.70454545E 00	0.15592317E 01	0.36383791E-00	0.15565970E 01	0.24400120E-00
0.18778231E 01	0.15879995E-00	0.69318181E 00	0.15871992E 01	0.35465590E-00	0.16255402E 01	0.22953539E-00
0.19253296E 01	0.14682265E-00	0.68181818E 00	0.16145995E 01	0.34498314E-00	0.16999666E 01	0.21576133E-00
0.19730938E 01	0.13560290E-00	0.67045454E 00	0.16414607E 01	0.33489367E-00	0.17803156E 01	0.20265219E-00
0.20211688E 01	0.12510123E-00	0.65909091E 00	0.16678094E 01	0.32445753E-00	0.18670762E 01	0.19018240E-00
0.20696418E 01	0.11527887E-00	0.64772727E 00	0.16936728E 01	0.31373870E-00	0.19608071E 01	0.17832590E-00
0.21184685E 01	0.10610118E-00	0.63636363E 00	0.17190693E 01	0.30279914E-00	0.20621118E 01	0.16706029E-00
0.21677390E 01	0.97534245E-01	0.62500000E 00	0.17440177E 01	0.29169756E-00	0.21716586E 01	0.15636386E-00
0.22175043E 01	0.89545276E-01	0.61363636E 00	0.17685357E 01	0.28048752E-00	0.22902019E 01	0.14621476E-00
0.22678084E 01	0.82103066E-01	0.60227273E 00	0.17926391E 01	0.26921868E-00	0.24185839E 01	0.13659185E-00
0.23187295E 01	0.75177081E-01	0.59090909E 00	0.18163445E 01	0.25793753E-00	0.25577445E 01	0.12747454E-00
0.23703145E 01	0.68738278E-01	0.57954545E 00	0.18396667E 01	0.24668503E-00	0.27087557E 01	0.11884197E-00
0.24226227E 01	0.62758942E-01	0.56818181E 00	0.18626197E 01	0.23549951E-00	0.28728150E 01	0.11067434E-00
0.24757843E 01	0.57211502E-01	0.55681818E 00	0.18852210E 01	0.22441288E-00	0.30513216E 01	0.10295052E-00
0.25296669E 01	0.52072371E-01	0.54545454E 00	0.19074761E 01	0.21346185E-00	0.32457294E 01	0.95654941E-01
0.25844122E 01	0.47318092E-01	0.53409091E 00	0.19293925E 01	0.20267795E-00	0.34577020E 01	0.88770911E-01
0.26400854E 01	0.42925884E-01	0.52272727E 00	0.19509783E 01	0.19208889E-00	0.36891273E 01	0.82281601E-01
0.26967164E 01	0.38874403E-01	0.51136363E 00	0.19722383E 01	0.18172160E-00	0.39420880E 01	0.76171608E-01
0.27544916E 01	0.35141903E-01	0.50000000E 00	0.19931838E 01	0.17159449E-00	0.42190776E 01	0.70422912E-01
0.28134485E 01	0.31708036E-01	0.48863636E-00	0.20138239E 01	0.16172569E-00	0.45228890E 01	0.65019165E-01
0.28736766E 01	0.28553561E-01	0.47727273E-00	0.20341668E 01	0.15213110E-00	0.48567083E 01	0.59944624E-01
0.29352937E 01	0.25660043E-01	0.46590909E-00	0.20542210E 01	0.14282329E-00	0.52242216E 01	0.55183601E-01
0.29983395E 01	0.23010325E-01	0.45454545E-00	0.20739925E 01	0.13381582E-00	0.56295439E 01	0.50722241E-01
0.30629507E 01	0.20587995E-01	0.44318181E-00	0.20934872E 01	0.12511805E-00	0.60774840E 01	0.46546248E-01
0.31292467E 01	0.18377442E-01	0.43181818E-00	0.21127110E 01	0.11673780E-00	0.65735820E 01	0.42641911E-01
0.31974963E 01	0.16363355E-01	0.42045454E-00	0.21316746E 01	0.10867840E-00	0.71244467E 01	0.38994808E-01
0.32674368E 01	0.14532514E-01	0.40909091E-00	0.21503761E 01	0.10094808E-00	0.77373074E 01	0.35593816E-01
0.33393833E 01	0.12871935E-01	0.39772727E-00	0.21688166E 01	0.93551893E-01	0.84206136E 01	0.32427409E-01
0.34134960E 01	0.11369141E-01	0.38636363E-00	0.21869981E 01	0.86492167E-01	0.91842800E 01	0.29483926E-01
0.34899469E 01	0.10012352E-01	0.37500000E-00	0.22049215E 01	0.79770037E-01	0.10039841E 02	0.26752160E-01
0.35689459E 01	0.87902193E-02	0.36363636E-00	0.22225904E 01	0.73383772E-01	0.11001018E 02	0.24220689E-01
0.36507087E 01	0.76920822E-02	0.35227273E-00	0.22400075E 01	0.67330632E-01	0.12083988E 02	0.21878578E-01
0.37354814E 01	0.67079104E-02	0.34090909E-00	0.22571752E 01	0.61606730E-01	0.13307934E 02	0.19715279E-01
0.38236051E 01	0.58282156E-02	0.32954545E-00	0.22740972E 01	0.56206602E-01	0.14695866E 02	0.17720445E-01
0.39151945E 01	0.50442239E-02	0.31818181E-00	0.22907742E 01	0.51124919E-01	0.16275080E 02	0.15884495E-01
0.40106788E 01	0.43476605E-02	0.30681818E-00	0.23072077E 01	0.46355052E-01	0.18078531E 02	0.14198060E-01
0.41104499E 01	0.37307634E-02	0.29545454E-00	0.23233996E 01	0.41889392E-01	0.20146210E 02	0.12652069E-01
0.42149370E 01	0.31863179E-02	0.28409091E-00	0.23393504E 01	0.37719988E-01	0.22526682E 02	0.11237930E-01
0.43247030E 01	0.27075019E-02	0.27272727E-00	0.23550636E 01	0.33837225E-01	0.25280254E 02	0.99470609E-02
0.44403195E 01	0.22880080E-02	0.26136363E-00	0.23705421E 01	0.30231311E-01	0.28481589E 02	0.87713613E-02
0.45624713E 01	0.19219989E-02	0.25000000E-00	0.23857881E 01	0.26892188E-01	0.32223985E 02	0.77031393E-02
0.46914499E 01	0.16042513E-02	0.23863636E-00	0.24007952E 01	0.23811970E-01	0.36621259E 02	0.67358195E-02
0.48296857E 01	0.13294772E-02	0.22727273E-00	0.24155792E 01	0.20976134E-01	0.41828217E 02	0.58612228E-02

L-1396

TABLE V.- FLOW PROPERTIES OF CH_4-AIR COMBUSTION PRODUCTS - Continued

(a) $R_{eq} = 1.0$; $T_t = 2{,}200^{\circ}$ K; $T^* = 1{,}969.1^{\circ}$ K - Concluded

M	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.48584653E 01	0.12792595E-02	0.22499999E-00	0.24185102E 01	0.20437194E-01	0.42983340E 02	0.56967977E-02
0.48876452E 01	0.12305379E-02	0.22272727E-00	0.24214327E 01	0.19907452E-01	0.44180459E 02	0.55357470E-02
0.49172361E 01	0.11832779E-02	0.22045454E-00	0.24243468E 01	0.19386818E-01	0.45421529E 02	0.53780195E-02
0.49472487E 01	0.11374462E-02	0.21818181E-00	0.24272526E 01	0.18875200E-01	0.46708608E 02	0.52235644E-02
0.49776942E 01	0.10930094E-02	0.21590909E-00	0.24301501E 01	0.18372511E-01	0.48043879E 02	0.50723318E-02
0.50085843E 01	0.10499354E-02	0.21363636E-00	0.24330395E 01	0.17878664E-01	0.49429655E 02	0.49242727E-02
0.50399310E 01	0.10081924E-02	0.21136364E-00	0.24359207E 01	0.17393571E-01	0.50868379E 02	0.47793388E-02
0.50717473E 01	0.96774911E-03	0.20909090E-00	0.24387936E 01	0.16917146E-01	0.52362634E 02	0.46374826E-02
0.51040459E 01	0.92857484E-03	0.20681818E-00	0.24416588E 01	0.16449302E-01	0.53915172E 02	0.44986567E-02
0.51368404E 01	0.89063957E-03	0.20454545E-00	0.24445160E 01	0.15989954E-01	0.55528909E 02	0.43628152E-02
0.51663169E 01	0.85403083E-03	0.20227272E-00	0.24473558E 01	0.15541029E-01	0.57199321E 02	0.42304920E-02
0.52002161E 01	0.81861375E-03	0.20000000E-00	0.24501864E 01	0.15100683E-01	0.58935376E 02	0.41011316E-02
0.52347349E 01	0.78433360E-03	0.19772727E-00	0.24530096E 01	0.14668376E-01	0.60742223E 02	0.39745586E-02
0.52698907E 01	0.75116111E-03	0.19545455E-00	0.24558257E 01	0.14243992E-01	0.62623783E 02	0.38507205E-02
0.53057024E 01	0.71906762E-03	0.19318181E-00	0.24586351E 01	0.13827414E-01	0.64584253E 02	0.37295648E-02
0.53421888E 01	0.68802522E-03	0.19090909E-00	0.24614380E 01	0.13418528E-01	0.66628113E 02	0.36110409E-02
0.53793704E 01	0.65800697E-03	0.18863636E-00	0.24642348E 01	0.13017229E-01	0.68760181E 02	0.34951011E-02
0.54172675E 01	0.62898659E-03	0.18636363E-00	0.24670255E 01	0.12623413E-01	0.70985612E 02	0.33816984E-02
0.54559022E 01	0.60093851E-03	0.18409090E-00	0.24698105E 01	0.12236981E-01	0.73309937E 02	0.32707877E-02
0.54952971E 01	0.57383782E-03	0.18181818E-00	0.24725901E 01	0.11857835E-01	0.75739108E 02	0.31623251E-02
0.55354759E 01	0.54766035E-03	0.17954545E-00	0.24753645E 01	0.11485887E-01	0.78279521E 02	0.30562688E-02
0.55764630E 01	0.52238246E-03	0.17727272E-00	0.24781340E 01	0.11121044E-01	0.80938052E 02	0.29525777E-02
0.56182846E 01	0.49798116E-03	0.17500000E-00	0.24808988E 01	0.10763222E-01	0.83722130E 02	0.28512122E-02
0.56609672E 01	0.47443411E-03	0.17272727E-00	0.24836592E 01	0.10412340E-01	0.86639744E 02	0.27521345E-02
0.57045392E 01	0.45171947E-03	0.17045454E-00	0.24864155E 01	0.10068318E-01	0.89699543E 02	0.26553079E-02
0.57490295E 01	0.42981592E-03	0.16818181E-00	0.24891677E 01	0.97310815E-02	0.92910875E 02	0.25606965E-02
0.57944703E 01	0.40870274E-03	0.16590909E-00	0.24919164E 01	0.94005579E-02	0.96283833E 02	0.24682663E-02
0.58408928E 01	0.38835962E-03	0.16363636E-00	0.24946617E 01	0.90766765E-02	0.99829366E 02	0.23779839E-02
0.58883309E 01	0.36876681E-03	0.16136363E-00	0.24974036E 01	0.87593719E-02	0.10355934E 03	0.22898173E-02
0.59368205E 01	0.34990493E-03	0.15909091E-00	0.25001428E 01	0.84485783E-02	0.10748668E 03	0.22037350E-02
0.59940909E 01	0.33165104E-03	0.15681818E-00	0.25028952E 01	0.81417845E-02	0.11165972E 03	0.21190422E-02
0.60446741E 01	0.31408282E-03	0.15454545E-00	0.25056481E 01	0.78411075E-02	0.11606899E 03	0.20363040E-02
0.60962651E 01	0.29720546E-03	0.15227272E-00	0.25083978E 01	0.75470433E-02	0.12072387E 03	0.19556419E-02
0.61489022E 01	0.28100241E-03	0.15000000E-00	0.25111445E 01	0.72595804E-02	0.12564168E 03	0.18770397E-02
0.62026255E 01	0.26545711E-03	0.14772727E-00	0.25138879E 01	0.69787044E-02	0.13084123E 03	0.18004802E-02
0.62574777E 01	0.25055311E-03	0.14545454E-00	0.25166276E 01	0.67043979E-02	0.13634298E 03	0.17259458E-02
0.63135034E 01	0.23627388E-03	0.14318182E-00	0.25193641E 01	0.64366372E-02	0.14216918E 03	0.16534174E-02
0.63707501E 01	0.22260308E-03	0.14090909E-00	0.25220966E 01	0.61753975E-02	0.14834415E 03	0.15828758E-02
0.64292660E 01	0.20952439E-03	0.13863636E-00	0.25248253E 01	0.59206502E-02	0.15489434E 03	0.15143006E-02
0.64891098E 01	0.19702160E-03	0.13636363E-00	0.25275499E 01	0.56723636E-02	0.16184873E 03	0.14476711E-02
0.65503322E 01	0.18507858E-03	0.13409091E-00	0.25302704E 01	0.54305028E-02	0.16923903E 03	0.13829640E-02
0.66129944E 01	0.17367933E-03	0.13181816E-00	0.25329866E 01	0.51950287E-02	0.17710000E 03	0.13201628E-02
0.66771600E 01	0.16280800E-03	0.12954545E-00	0.25356984E 01	0.49659016E-02	0.18546976E 03	0.12592392E-02
0.67428962E 01	0.15244881E-03	0.12727273E-00	0.25384057E 01	0.47430758E-02	0.19439030E 03	0.12001716E-02
0.68102745E 01	0.14258617E-03	0.12500000E-00	0.25411081E 01	0.45265052E-02	0.20390776E 03	0.11429364E-02
0.68793711E 01	0.13320462E-03	0.12272727E-00	0.25438058E 01	0.43161391E-02	0.21407312E 03	0.10875090E-02
0.69502673E 01	0.12428887E-03	0.12045454E-00	0.25464986E 01	0.41119254E-02	0.22494265E 03	0.10338647E-02
0.70230497E 01	0.11582380E-03	0.11818182E-00	0.25491862E 01	0.39138085E-02	0.23657868E 03	0.98197811E-03
0.70978111E 01	0.10779445E-03	0.11590906E-00	0.25518686E 01	0.37217297E-02	0.24905031E 03	0.93182333E-03
0.71746507E 01	0.10018607E-03	0.11363636E-00	0.25545456E 01	0.35356288E-02	0.26243431E 03	0.88337418E-03
0.72536748E 01	0.92984091E-04	0.11136363E-00	0.25572171E 01	0.33554422E-02	0.27681619E 03	0.83660395E-03
0.73349971E 01	0.86174139E-04	0.10909090E-00	0.25598830E 01	0.31811046E-02	0.29229124E 03	0.79148567E-03
0.74187405E 01	0.79742057E-04	0.10681818E-00	0.25625432E 01	0.30125479E-02	0.30896612E 03	0.74799193E-03
0.75050365E 01	0.73673905E-04	0.10454545E-00	0.25651975E 01	0.28497022E-02	0.32696026E 03	0.70609510E-03
0.75940274E 01	0.67955940E-04	0.10227273E-00	0.25678458E 01	0.26924944E-02	0.34640788E 03	0.66576700E-03
0.76858660E 01	0.62574684E-04	0.99999999E-01	0.25704880E 01	0.25408507E-02	0.36746000E 03	0.62697949E-03
0.77807184E 01	0.57516854E-04	0.97727273E-01	0.25731239E 01	0.23946943E-02	0.39028715E 03	0.58970392E-03
0.78787640E 01	0.52769422E-04	0.95454545E-01	0.25757536E 01	0.22539468E-02	0.41508237E 03	0.55391151E-03
0.79801977E 01	0.48319608E-04	0.93181817E-01	0.25783767E 01	0.21185283E-02	0.44206458E 03	0.51957337E-03
0.80852312E 01	0.44154861E-04	0.90909091E-01	0.25809932E 01	0.19883565E-02	0.47148322E 03	0.48666025E-03
0.81940952E 01	0.40262891E-04	0.88636363E-01	0.25836030E 01	0.18633478E-02	0.50362293E 03	0.45514282E-03

L-1396

TABLE V.- FLOW PROPERTIES OF CH_4-AIR COMBUSTION PRODUCTS - Continued

(b) $R_{eq} = 0.7$; $T_t = 1,900^\circ$ K; $T^* = 1,678.7^\circ$ K

N_{Ma}	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.	0.09999999E 01	0.09999999E 01	0.	0.	0.	0.09999999E 01
0.32109787E-00	0.93754268E 00	0.98684210E 00	0.31911445E-00	0.60867875E-01	0.19443128E 01	0.95005909E 00
0.45654754E-00	0.87843052E 00	0.97368421E 00	0.45089149E-00	0.11539616E-00	0.14490671E 01	0.90219977E 00
0.56216787E 00	0.82252496E 00	0.96052631E 00	0.55170766E 00	0.16399109E-00	0.12476609E 01	0.85636255E 00
0.65273763E 00	0.76966388E 00	0.94736842E 00	0.63647024E 00	0.20706444E-00	0.11399357E 01	0.81246519E 00
0.73392203E 00	0.71969981E 00	0.93421052E 00	0.71095433E 00	0.24499729E-00	0.10761882E 01	0.77043020E 00
0.80862929E 00	0.67249451E 00	0.92105263E 00	0.77812304E 00	0.27814776E-00	0.10374818E 01	0.73018760E 00
0.87859538E 00	0.62791334E 00	0.90789473E 00	0.83974269E 00	0.30685551E-00	0.10148926E 01	0.69166675E 00
0.94493074E 00	0.58583426E 00	0.89473684E 00	0.89695764E 00	0.33143866E-00	0.10036368E 01	0.65480915E 00
0.10084242E 01	0.54613865E 00	0.88157894E 00	0.95056539E 00	0.35219872E-00	0.10009261E 01	0.61955407E 00
0.10696507E 01	0.50871235E 00	0.86842105E 00	0.10011479E 01	0.36942167E-00	0.10050408E 01	0.58584306E 00
0.11290588E 01	0.47344424E-00	0.85526315E 00	0.10491476E 01	0.38337814E-00	0.10148855E 01	0.55361722E 00
0.11869655E 01	0.44023228E-00	0.84210526E 00	0.10949029E 01	0.39432399E-00	0.10297463E 01	0.52282624E 00
0.12436561E 01	0.40897737E-00	0.82894737E 00	0.11386846E 01	0.40250091E-00	0.10491665E 01	0.49341844E-00
0.12993587E 01	0.37958404E-00	0.81578947E 00	0.11807127E 01	0.40813795E-00	0.10728650E 01	0.46534375E-00
0.13542683E 01	0.35196014E-00	0.80263157E 00	0.12211698E 01	0.41145151E-00	0.11006905E 01	0.43855287E-00
0.14085440E 01	0.32601862E-00	0.78947368E 00	0.12602065E 01	0.41264654E-00	0.11325864E 01	0.41300014E-00
0.14623316E 01	0.30167560E-00	0.77631579E 00	0.12979508E 01	0.41191621E-00	0.11685766E 01	0.38864030E-00
0.15157588E 01	0.27885047E-00	0.76315789E 00	0.13345125E 01	0.40944296E-00	0.12087516E 01	0.36542945E-00
0.15689480E 01	0.25746531E-00	0.75000000E 00	0.13699872E 01	0.40539835E-00	0.12532634E 01	0.34332415E-00
0.16219851E 01	0.23744692E-00	0.73684210E 00	0.14044560E 01	0.39994497E-00	0.13023141E 01	0.32228446E-00
0.16749739E 01	0.21872462E-00	0.72368421E 00	0.14379904E 01	0.39323550E-00	0.13561605E 01	0.30227078E-00
0.17280054E 01	0.20123050E-00	0.71052631E 00	0.14706538E 01	0.38541353E-00	0.14151136E 01	0.28324451E-00
0.17811822E 01	0.18489867E-00	0.69736842E 00	0.15025038E 01	0.37661306E-00	0.14795446E 01	0.26516709E-00
0.18345410E 01	0.16966791E-00	0.68421052E 00	0.15335887E 01	0.36696155E-00	0.15498731E 01	0.24800372E-00
0.18881792E 01	0.15547890E-00	0.67105263E 00	0.15639521E 01	0.35657813E-00	0.16265843E 01	0.23171984E-00
0.19421742E 01	0.14227459E-00	0.65789473E 00	0.15936340E 01	0.34557401E-00	0.17102333E 01	0.21628146E-00
0.19966121E 01	0.12999994E-00	0.64473684E 00	0.16226713E 01	0.33405243E-00	0.18014564E 01	0.20165498E-00
0.20515455E 01	0.11860309E-00	0.63157894E 00	0.16510954E 01	0.32211102E-00	0.19009664E 01	0.18780910E-00
0.21070615E 01	0.10803409E-00	0.61842105E 00	0.16789357E 01	0.30984005E-00	0.20095756E 01	0.17471284E-00
0.21632389E 01	0.98245031E-01	0.60526315E 00	0.17062190E 01	0.29732316E-00	0.21282069E 01	0.16233592E-00
0.22201872E 01	0.89189526E-01	0.59210526E 00	0.17329716E 01	0.28463657E-00	0.22579201E 01	0.15064795E-00
0.22779090E 01	0.80824607E-01	0.57894737E 00	0.17592137E 01	0.27185323E-00	0.23998933E 01	0.13962164E-00
0.23365229E 01	0.73108734E-01	0.56578947E 00	0.17849649E 01	0.25903978E-00	0.25554716E 01	0.12922975E-00
0.23961183E 01	0.66002056E-01	0.55263157E 00	0.18102437E 01	0.24625687E-00	0.27261925E 01	0.11944547E-00
0.24568308E 01	0.59465849E-01	0.53947368E 00	0.18350697E 01	0.23355789E-00	0.29138410E 01	0.11024143E-00
0.25186434E 01	0.53464773E-01	0.52631579E 00	0.18594551E 01	0.22099616E-00	0.31203894E 01	0.10159416E-00
0.25817075E 01	0.47964557E-01	0.51315789E 00	0.18834125E 01	0.20861831E-00	0.33481189E 01	0.93479621E-01
0.26461346E 01	0.42932306E-01	0.50000000E 00	0.19069544E 01	0.19646588E-00	0.35996561E 01	0.85874047E-01
0.27120339E 01	0.38336883E-01	0.48684210E-00	0.19300911E 01	0.18457697E-00	0.38780028E 01	0.78754858E-01
0.27795647E 01	0.34148001E-01	0.47368421E-00	0.19528352E 01	0.17298186E-00	0.41867098E 01	0.72098263E-01
0.28488597E 01	0.30337082E-01	0.46052631E-00	0.19751982E 01	0.16170860E-00	0.45298664E 01	0.65882059E-01
0.29200760E 01	0.26877083E-01	0.44736842E-00	0.19971905E 01	0.15078121E-00	0.49122459E 01	0.60084672E-01
0.29934424E 01	0.23742124E-01	0.43421052E-00	0.20188238E 01	0.14021848E-00	0.53395049E 01	0.54684453E-01
0.30689833E 01	0.20908411E-01	0.42105263E-00	0.20401044E 01	0.13004031E-00	0.58181144E 01	0.49662505E-01
0.31469733E 01	0.18353208E-01	0.40789473E-00	0.20610396E 01	0.12026097E-00	0.63557889E 01	0.44999479E-01
0.32276407E 01	0.16054955E-01	0.39473684E-00	0.20816363E 01	0.11089174E-00	0.69616704E 01	0.40676627E-01
0.33113547E 01	0.13992973E-01	0.38157894E-00	0.21019050E 01	0.10193903E-00	0.76468121E 01	0.36674970E-01
0.33980672E 01	0.12148628E-01	0.36842105E-00	0.21218471E 01	0.93411373E-01	0.84240741E 01	0.32978205E-01
0.34882317E 01	0.10504054E-01	0.35526315E-00	0.21414659E 01	0.85313536E-01	0.93089583E 01	0.29569980E-01
0.35822029E 01	0.90423306E-02	0.34210526E-00	0.21607655E 01	0.77647014E-01	0.10320263E 02	0.26434123E-01
0.36803231E 01	0.77477228E-02	0.32894737E-00	0.21797471E 01	0.70412332E-01	0.11480617E 02	0.23555479E-01
0.37832339E 01	0.66050129E-02	0.31578947E-00	0.21984184E 01	0.63604170E-01	0.12818365E 02	0.20918009E-01
0.38914008E 01	0.56001471E-02	0.30263157E-00	0.22167854E 01	0.57216518E-01	0.14368456E 02	0.18506723E-01
0.40054467E 01	0.47200821E-02	0.28947368E-00	0.22348536E 01	0.51242172E-01	0.16174446E 02	0.16307402E-01
0.41256493E 01	0.39531127E-02	0.27631579E-00	0.22526174E 01	0.45676970E-01	0.18289339E 02	0.14307965E-01
0.42541748E 01	0.32872922E-02	0.26315789E-00	0.22700971E 01	0.40504166E-01	0.20785123E 02	0.12492986E-01
0.42809010E 01	0.31653152E-02	0.26052631E-00	0.22735602E 01	0.39515475E-01	0.21337677E 02	0.12150936E-01
0.43079884E 01	0.30468784E-02	0.25789473E-00	0.22770125E 01	0.38541839E-01	0.21909925E 02	0.11815634E-01

L-1390

TABLE V.- FLOW PROPERTIES OF CH_4-AIR COMBUSTION PRODUCTS - Concluded

(b) $R_{eq} = 0.7$; $T_t = 1,900^\circ$ K; $T^* = 1,678.7^\circ$ K - Concluded

N_{Ma}	p/p_t	T/T_t	V/a_t	q/p_t	A/A^*	ρ/ρ_t
0.43354465E 01	0.29319040E-02	0.25526316E-00	0.22804543E 01	0.37583160E-01	0.22502767E 02	0.11486983E-01
0.43632852E 01	0.28203156E-02	0.25263157E-00	0.22838854E 01	0.36639340E-01	0.23117164E 02	0.11164889E-01
0.43915147E 01	0.27120378E-02	0.25000000E-00	0.22873061E 01	0.35710280E-01	0.23754118E 02	0.10849260E-01
0.44201456E 01	0.26069966E-02	0.24736842E-00	0.22907164E 01	0.34795877E-01	0.24414701E 02	0.10539999E-01
0.44491890E 01	0.25051192E-02	0.24473684E-00	0.22941164E 01	0.33896033E-01	0.25100040E 02	0.10237017E-01
0.44786563E 01	0.24063347E-02	0.24210526E-00	0.22975061E 01	0.33010652E-01	0.25811334E 02	0.99402242E-02
0.45085593E 01	0.23105725E-02	0.23947368E-00	0.23008857E 01	0.32139628E-01	0.26549850E 02	0.96495305E-02
0.45389102E 01	0.22177640E-02	0.23684210E-00	0.23042552E 01	0.31282866E-01	0.27316932E 02	0.93648495E-02
0.45663477E 01	0.21281213E-02	0.23421052E-00	0.23076041E 01	0.30443987E-01	0.28110440E 02	0.90872892E-02
0.45976898E 01	0.20413250E-02	0.23157895E-00	0.23109413E 01	0.29619645E-01	0.28934562E 02	0.88157135E-02
0.46295901E 01	0.19572474E-02	0.22894736E-00	0.23142692E 01	0.28808906E-01	0.29791678E 02	0.85497703E-02
0.46620650E 01	0.18758205E-02	0.22631579E-00	0.23175881E 01	0.28011598E-01	0.30683596E 02	0.82893561E-02
0.46951313E 01	0.17969780E-02	0.22368421E-00	0.23208985E 01	0.27227557E-01	0.31612246E 02	0.80343700E-02
0.47288065E 01	0.17206557E-02	0.22105262E-00	0.23242005E 01	0.26456624E-01	0.32579695E 02	0.77847143E-02
0.47631090E 01	0.16467912E-02	0.21842105E-00	0.23274945E 01	0.25698654E-01	0.33588155E 02	0.75402971E-02
0.47980577E 01	0.15753237E-02	0.21578947E-00	0.23307810E 01	0.24953497E-01	0.34640004E 02	0.73010267E-02
0.48336726E 01	0.15061937E-02	0.21315789E-00	0.23340600E 01	0.24221017E-01	0.35737773E 02	0.70668158E-02
0.48699741E 01	0.14393436E-02	0.21052631E-00	0.23373320E 01	0.23501083E-01	0.36884202E 02	0.68375811E-02
0.49069841E 01	0.13747174E-02	0.20789474E-00	0.23405973E 01	0.22793566E-01	0.38082226E 02	0.66132402E-02
0.49447250E 01	0.13122599E-02	0.20526315E-00	0.23438561E 01	0.22098342E-01	0.39334998E 02	0.63937142E-02
0.49832200E 01	0.12519181E-02	0.20263158E-00	0.23471088E 01	0.21415300E-01	0.40645915E 02	0.61789283E-02
0.50224939E 01	0.11936397E-02	0.20000000E-00	0.23503556E 01	0.20744328E-01	0.42018646E 02	0.59688088E-02
0.50625724E 01	0.11373740E-02	0.19736842E-00	0.23535969E 01	0.20085321E-01	0.43457142E 02	0.57632843E-02
0.51034823E 01	0.10830714E-02	0.19473684E-00	0.23568329E 01	0.19438177E-01	0.44965677E 02	0.55622865E-02
0.51452515E 01	0.10306834E-02	0.19210526E-00	0.23600640E 01	0.18802800E-01	0.46548867E 02	0.53657495E-02
0.51879096E 01	0.98016270E-03	0.18947368E-00	0.23632904E 01	0.18179101E-01	0.48211712E 02	0.51736096E-02
0.52314875E 01	0.93146314E-03	0.18684210E-00	0.23665124E 01	0.17566994E-01	0.49959628E 02	0.49858051E-02
0.52760173E 01	0.88453951E-03	0.18421052E-00	0.23697304E 01	0.16966396E-01	0.51798499E 02	0.48022765E-02
0.53282279E 01	0.83909933E-03	0.18157894E-00	0.23729626E 01	0.16372636E-01	0.53750206E 02	0.46215989E-02
0.53746688E 01	0.79532822E-03	0.17894737E-00	0.23761944E 01	0.15789703E-01	0.55810493E 02	0.44449354E-02
0.54220285E 01	0.75323948E-03	0.17631578E-00	0.23794221E 01	0.15218568E-01	0.57983650E 02	0.42725410E-02
0.54703412E 01	0.71279428E-03	0.17368421E-00	0.23826455E 01	0.14659247E-01	0.60277560E 02	0.41043864E-02
0.55196438E 01	0.67395386E-03	0.17105263E-00	0.23858643E 01	0.14111749E-01	0.62700754E 02	0.39404405E-02
0.55699747E 01	0.63667966E-03	0.16842105E-00	0.23890787E 01	0.13576081E-01	0.65262524E 02	0.37806717E-02
0.56213743E 01	0.60093300E-03	0.16578947E-00	0.23922881E 01	0.13052239E-01	0.67972982E 02	0.36250456E-02
0.56738859E 01	0.56667547E-03	0.16315789E-00	0.23954928E 01	0.12540215E-01	0.70843128E 02	0.34735271E-02
0.57275548E 01	0.53386871E-03	0.16052631E-00	0.23986924E 01	0.12039994E-01	0.73884983E 02	0.33260793E-02
0.57824291E 01	0.50247452E-03	0.15789473E-00	0.24018867E 01	0.11551553E-01	0.77111650E 02	0.31826638E-02
0.58385600E 01	0.47245497E-03	0.15526316E-00	0.24050758E 01	0.11074866E-01	0.80537498E 02	0.30432412E-02
0.58960012E 01	0.44377231E-03	0.15263157E-00	0.24082594E 01	0.10609899E-01	0.84178242E 02	0.29077706E-02
0.59548105E 01	0.41638900E-03	0.15000000E-00	0.24114373E 01	0.10156612E-01	0.88051134E 02	0.27762102E-02
0.60150486E 01	0.39026774E-03	0.14736842E-00	0.24146096E 01	0.97149595E-02	0.92175131E 02	0.26485160E-02
0.60767806E 01	0.36537164E-03	0.14473684E-00	0.24177758E 01	0.92848898E-02	0.96571092E 02	0.25246438E-02
0.61400753E 01	0.34166395E-03	0.14210526E-00	0.24209361E 01	0.88663442E-02	0.10126202E 03	0.24045476E-02
0.62050067E 01	0.31910839E-03	0.13947368E-00	0.24240902E 01	0.84592612E-02	0.10627332E 03	0.22881807E-02
0.62716533E 01	0.29766891E-03	0.13684210E-00	0.24272379E 01	0.80635704E-02	0.11163305E 03	0.21754951E-02
0.63400992E 01	0.27730997E-03	0.13421052E-00	0.24303792E 01	0.76791995E-02	0.11737240E 03	0.20664422E-02
0.64104342E 01	0.25799623E-03	0.13157894E-00	0.24335140E 01	0.73060664E-02	0.12352593E 03	0.19609717E-02
0.64827548E 01	0.23969296E-03	0.12894736E-00	0.24366421E 01	0.69440882E-02	0.13013209E 03	0.18590333E-02
0.65571642E 01	0.22236569E-03	0.12631579E-00	0.24397632E 01	0.65931728E-02	0.13723382E 03	0.17605749E-02
0.66337734E 01	0.20598049E-03	0.12368421E-00	0.24428774E 01	0.62532262E-02	0.14487903E 03	0.16655443E-02
0.67127021E 01	0.19050382E-03	0.12105263E-00	0.24459846E 01	0.59241473E-02	0.15312137E 03	0.15738880E-02
0.67940788E 01	0.17590269E-03	0.11842105E-00	0.24490844E 01	0.56058314E-02	0.16202115E 03	0.14855523E-02
0.68780427E 01	0.16214453E-03	0.11578947E-00	0.24521770E 01	0.52981687E-02	0.17164610E 03	0.14004821E-02
0.69647438E 01	0.14919731E-03	0.11315789E-00	0.24552621E 01	0.50010454E-02	0.18207277E 03	0.13186225E-02
0.70543450E 01	0.13702951E-03	0.11052631E-00	0.24583395E 01	0.47143421E-02	0.19338765E 03	0.12399175E-02
0.71470225E 01	0.12561012E-03	0.10789473E-00	0.24614093E 01	0.44379353E-02	0.20568889E 03	0.11643103E-02
0.72429687E 01	0.11490870E-03	0.10526315E-00	0.24644711E 01	0.41716984E-02	0.21908810E 03	0.10917442E-02
0.73423925E 01	0.10489532E-03	0.10263158E-00	0.24675250E 01	0.39154994E-02	0.23371270E 03	0.10221614E-02

L-936

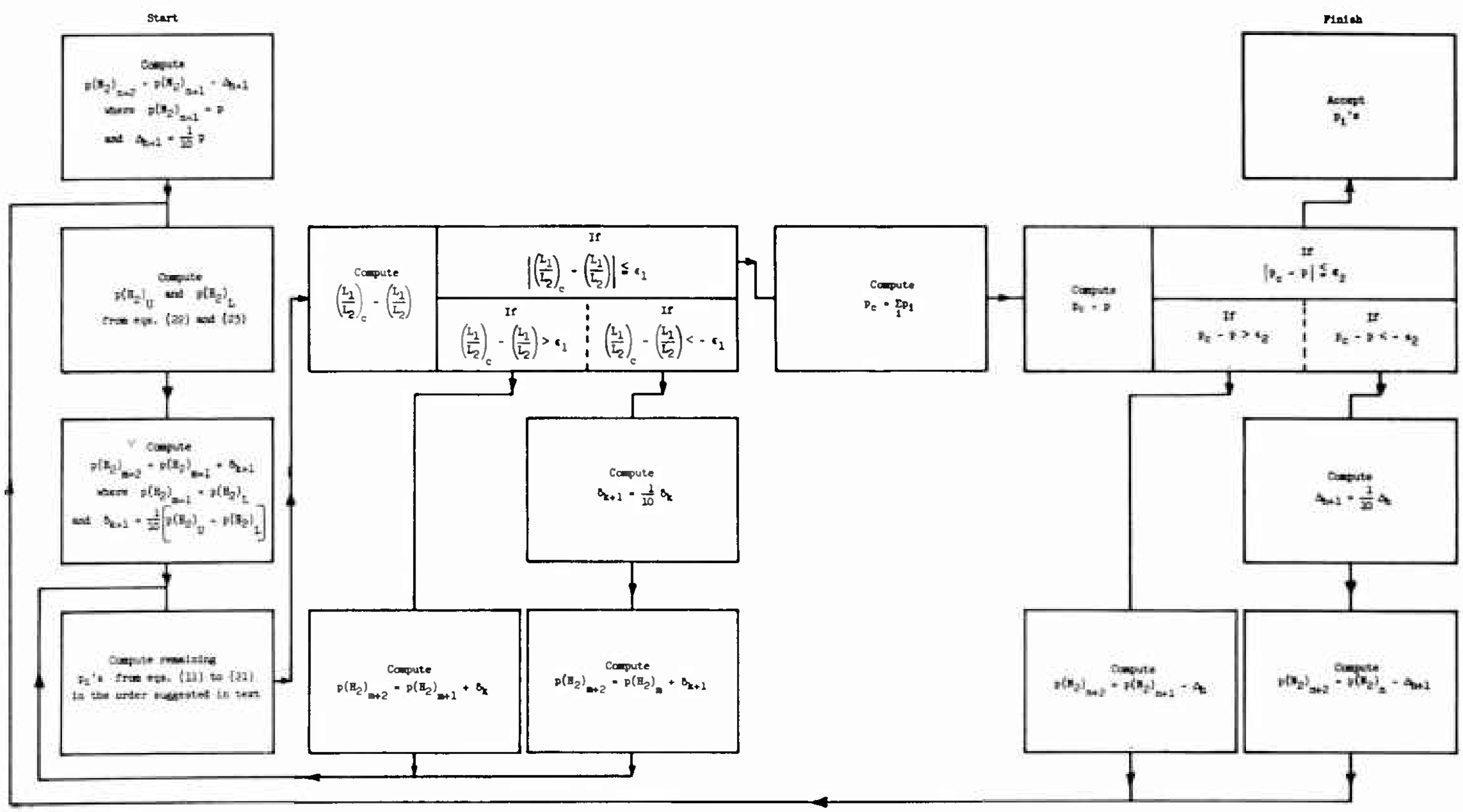
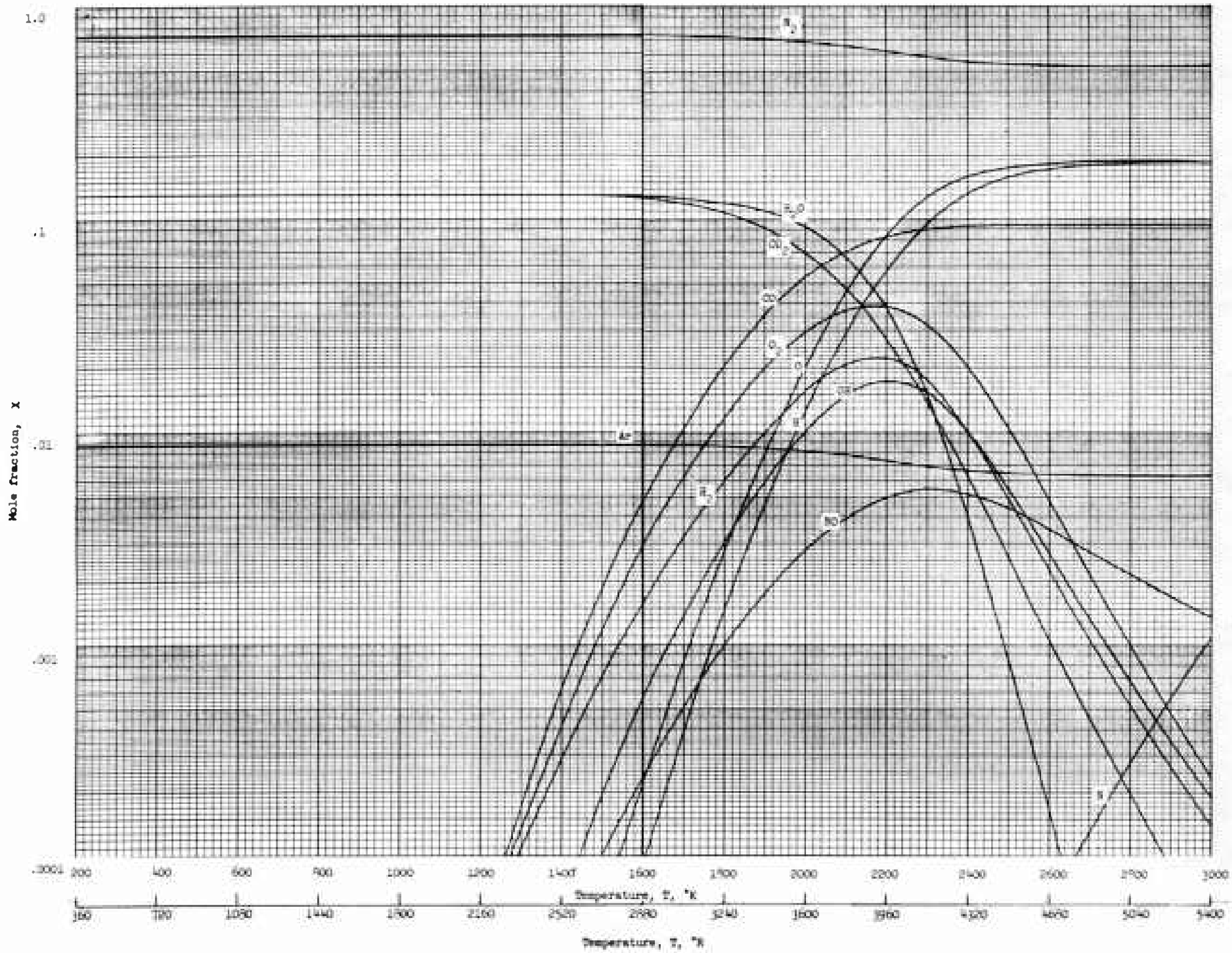


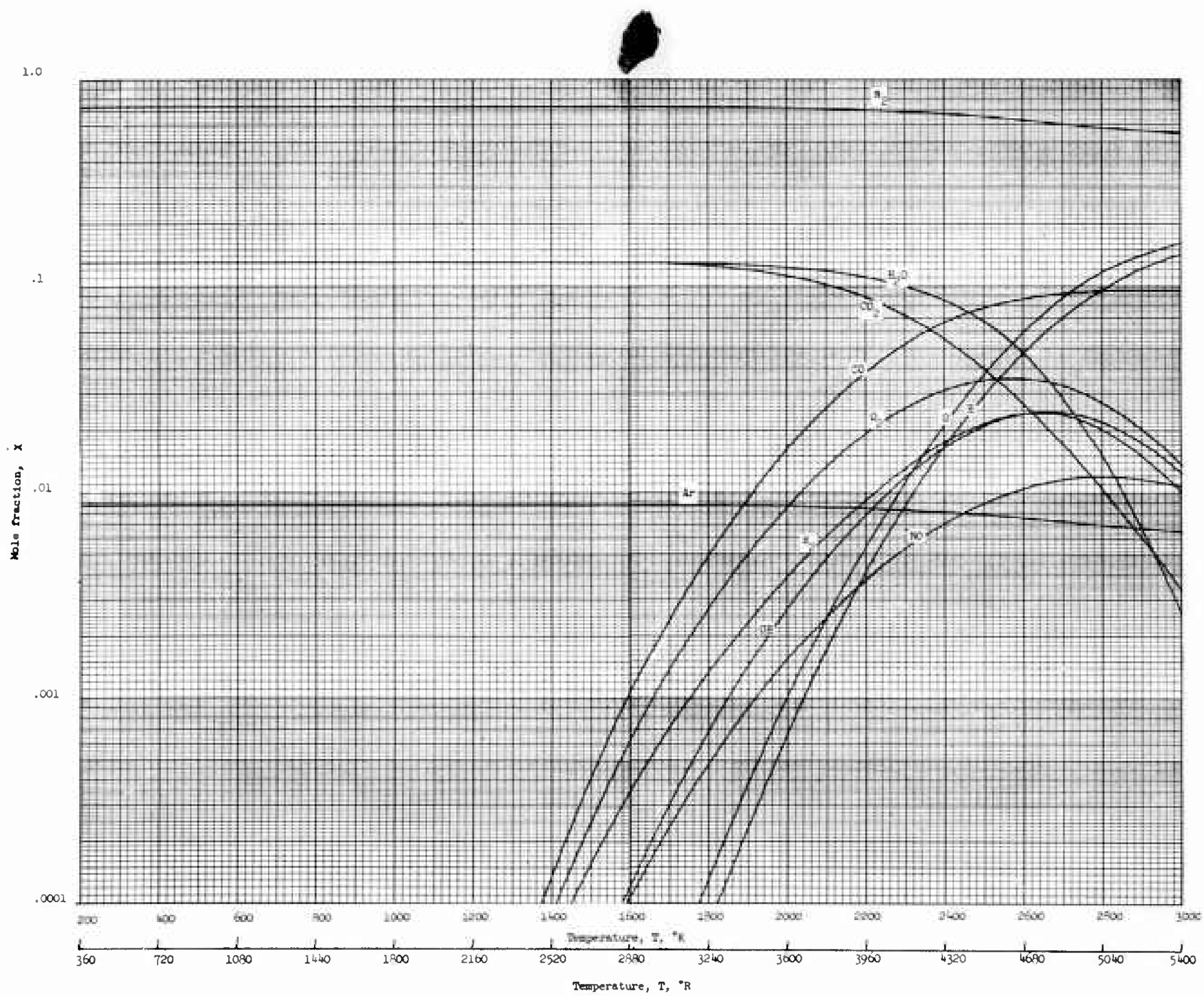
Figure 1.- Numerical step procedure used to compute the partial pressures at a constant pressure and temperature.

L-1396



(a) R_{eq} = 1.0; p = 0.0001 atmosphere.

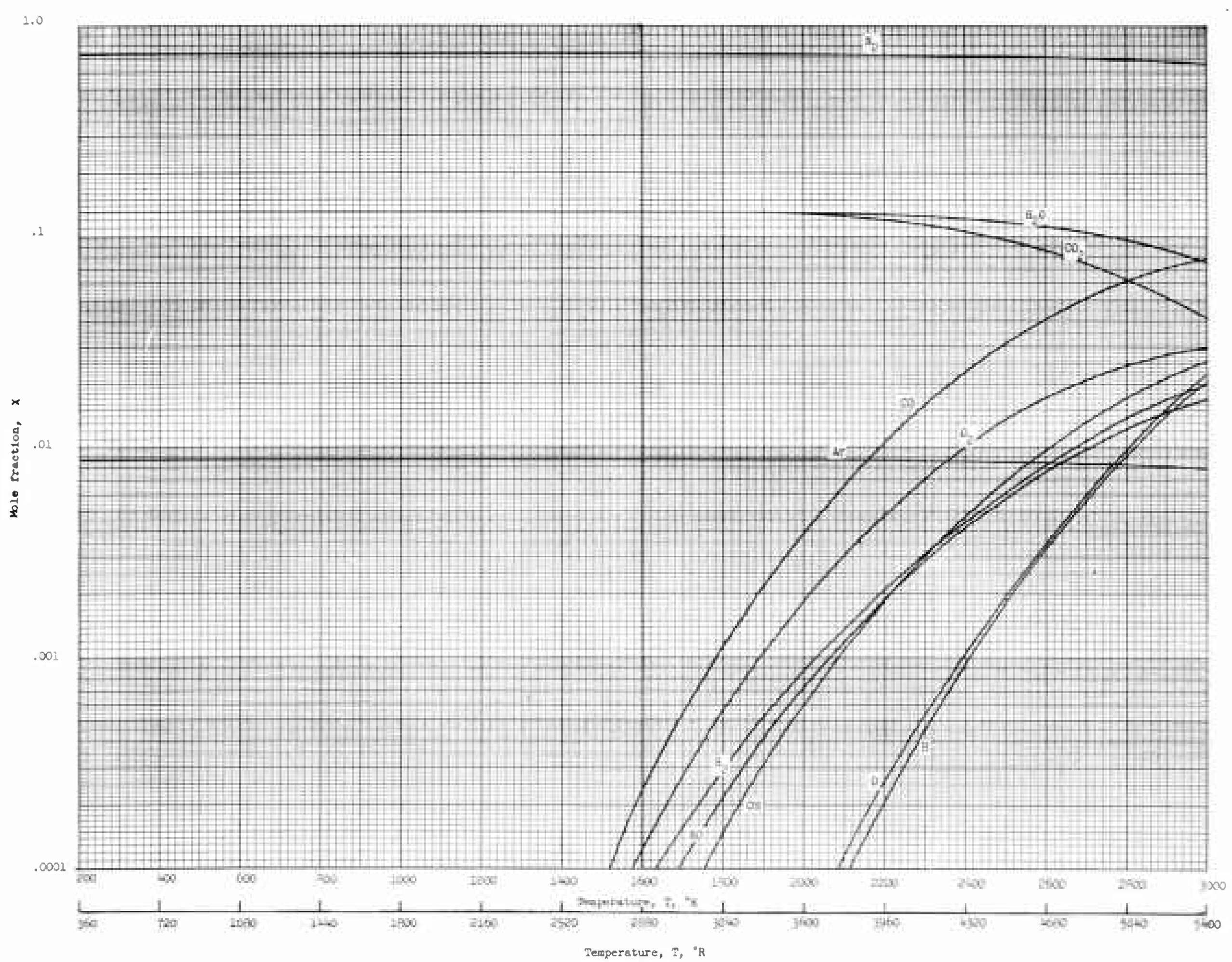
Figure 2.- Equilibrium composition of C[illegible]$_4$-air combustion products.



(b) $R_{eq} = 1.0$; $p = 0.01$ atmosphere.

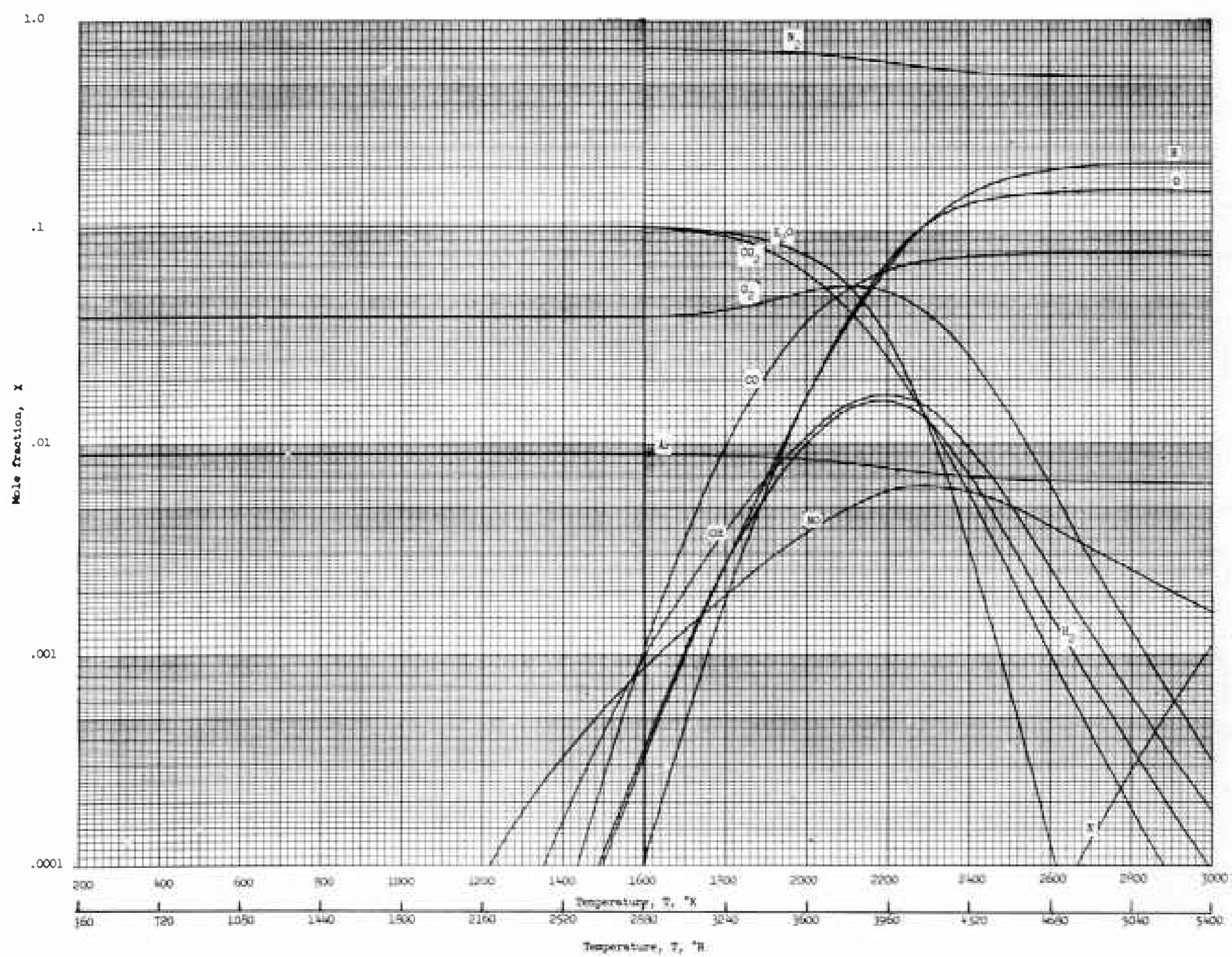
Figure 2.- Continued.

L-1396



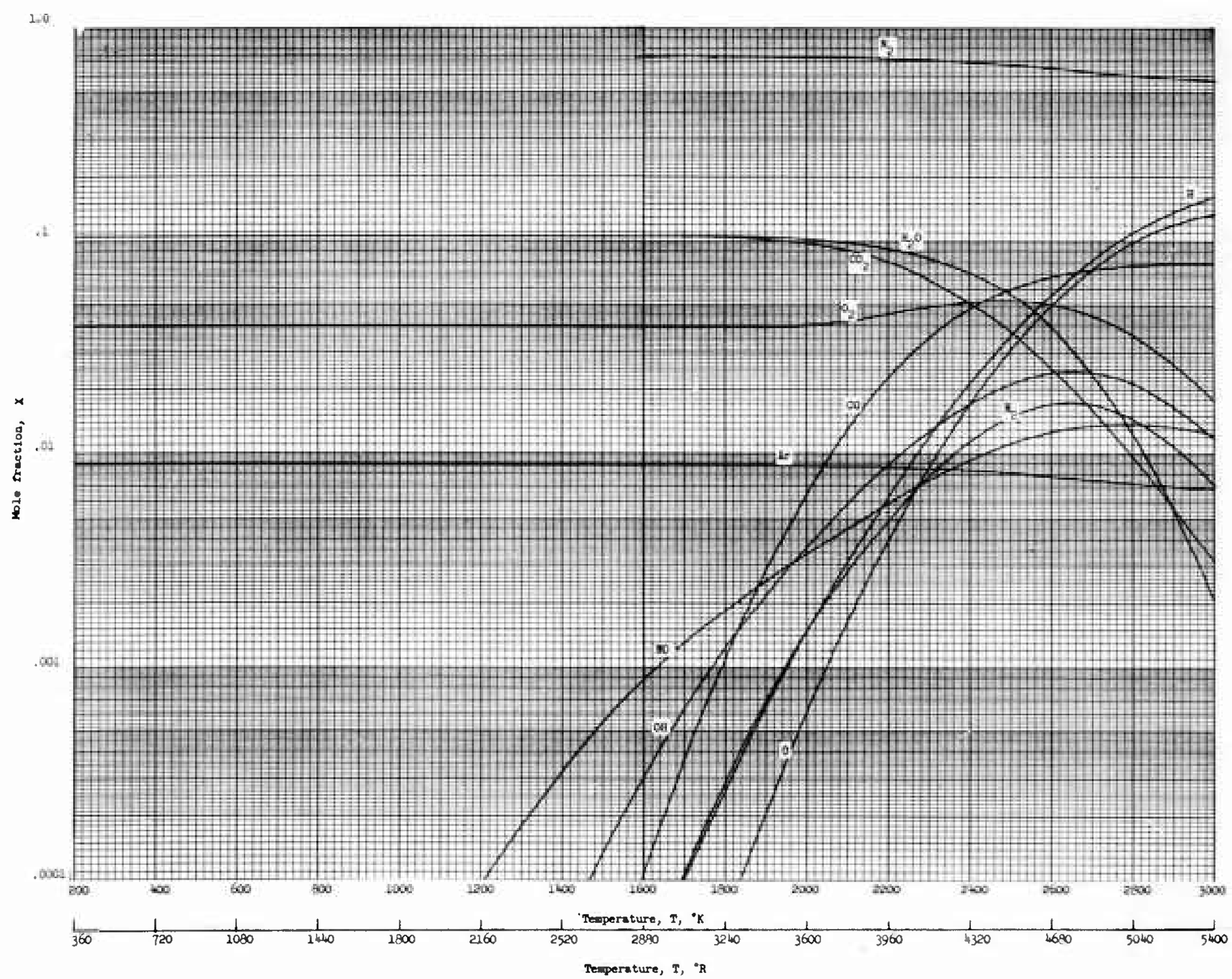
(c) $R_{eq} = 1.0$; p = 1.0 atmosphere.

Figure 2.- Continued.



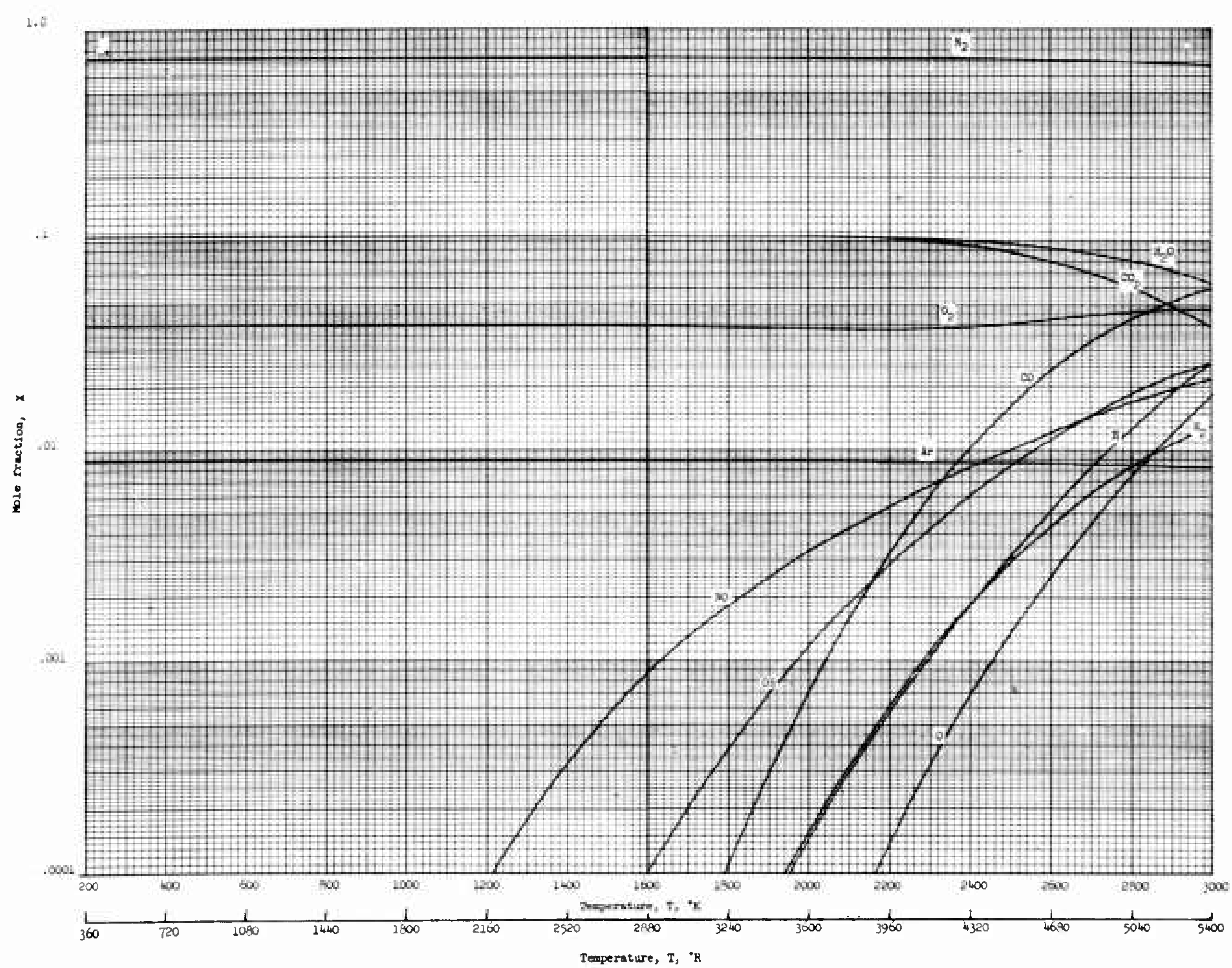
(d) $R_{eq} = 0.8$; $p = 0.0001$ atmosphere.

Figure 2.- Continued.



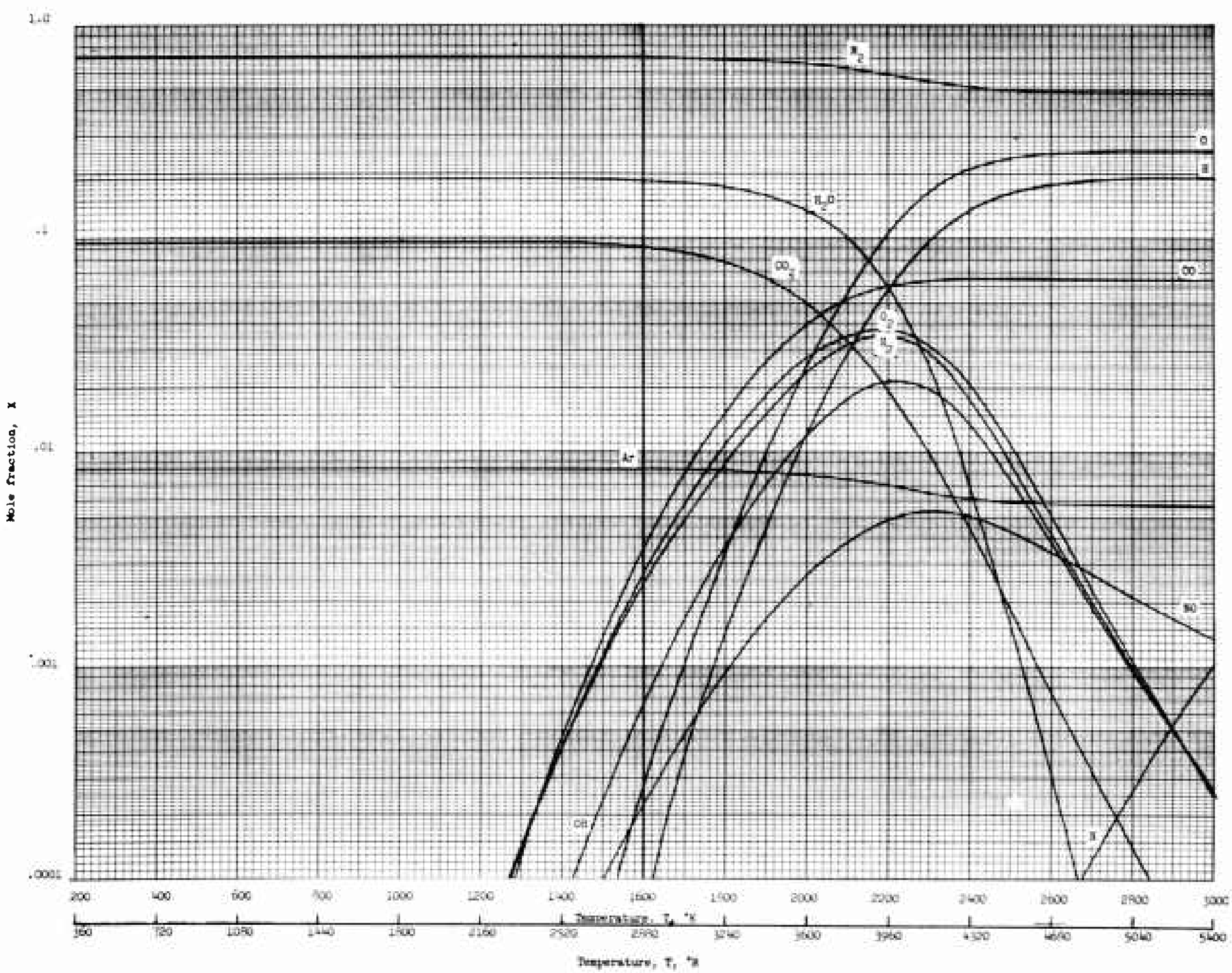
(e) $R_{eq} = 0.8$; $p = 0.01$ atmosphere.

Figure 2.- Continued.



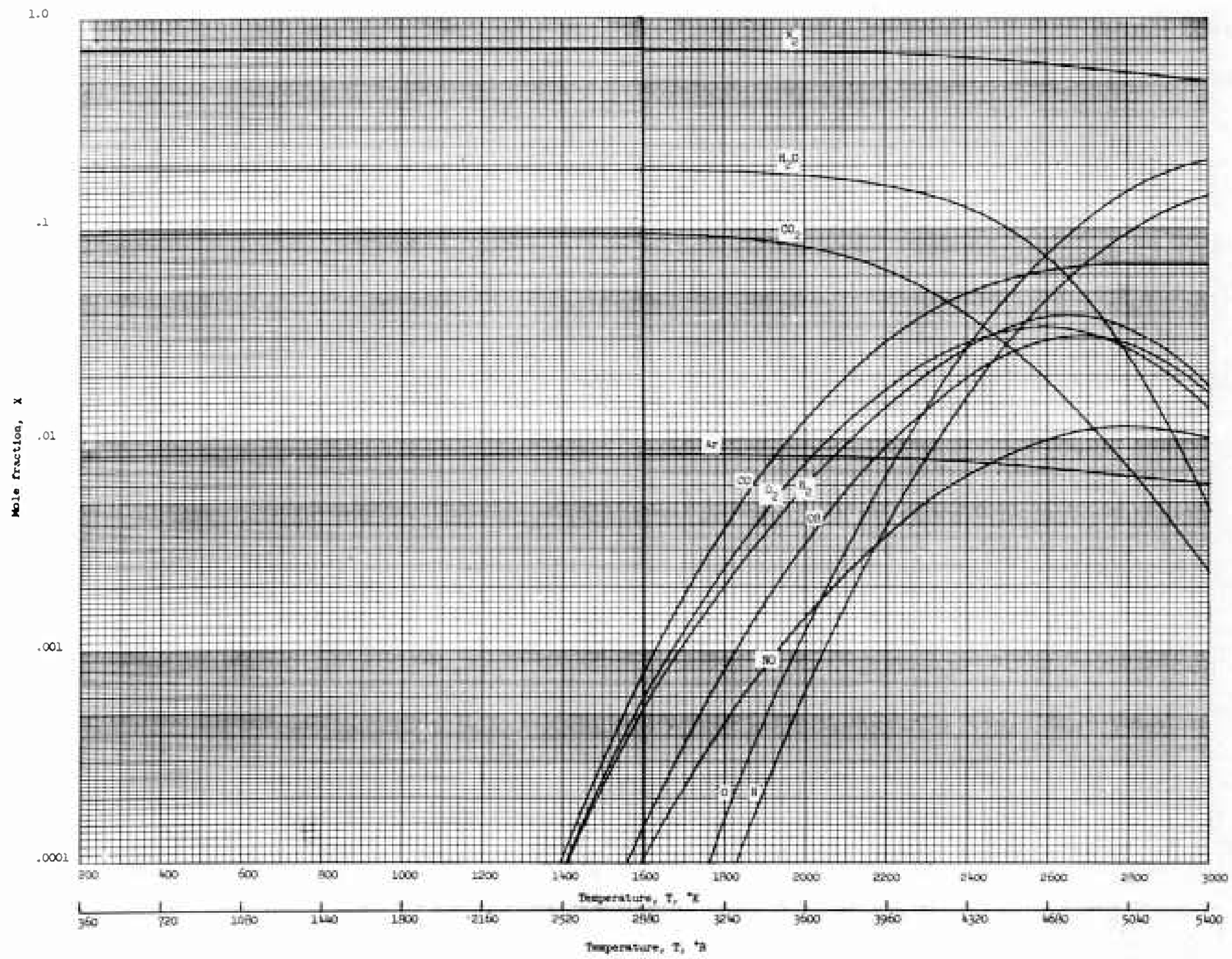
(f) $R_{eq} = 0.8$; p = 1.0 atmosphere.

Figure 2.- Concluded.



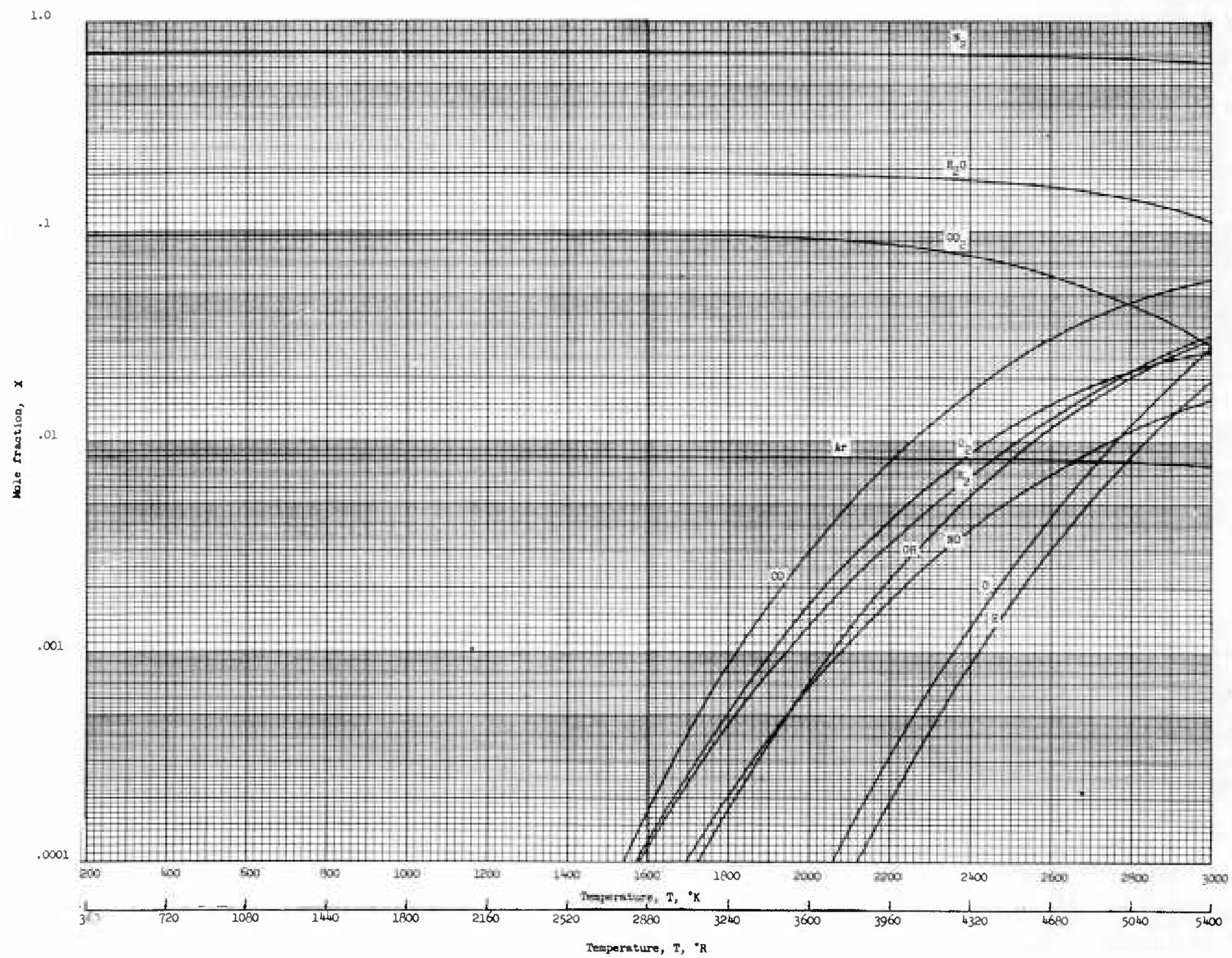
(a) $R_{eq} = 1.0$; $p = 0.0001$ atmosphere.

Figure 3.- Equilibrium composition of CH_4-air combustion products.



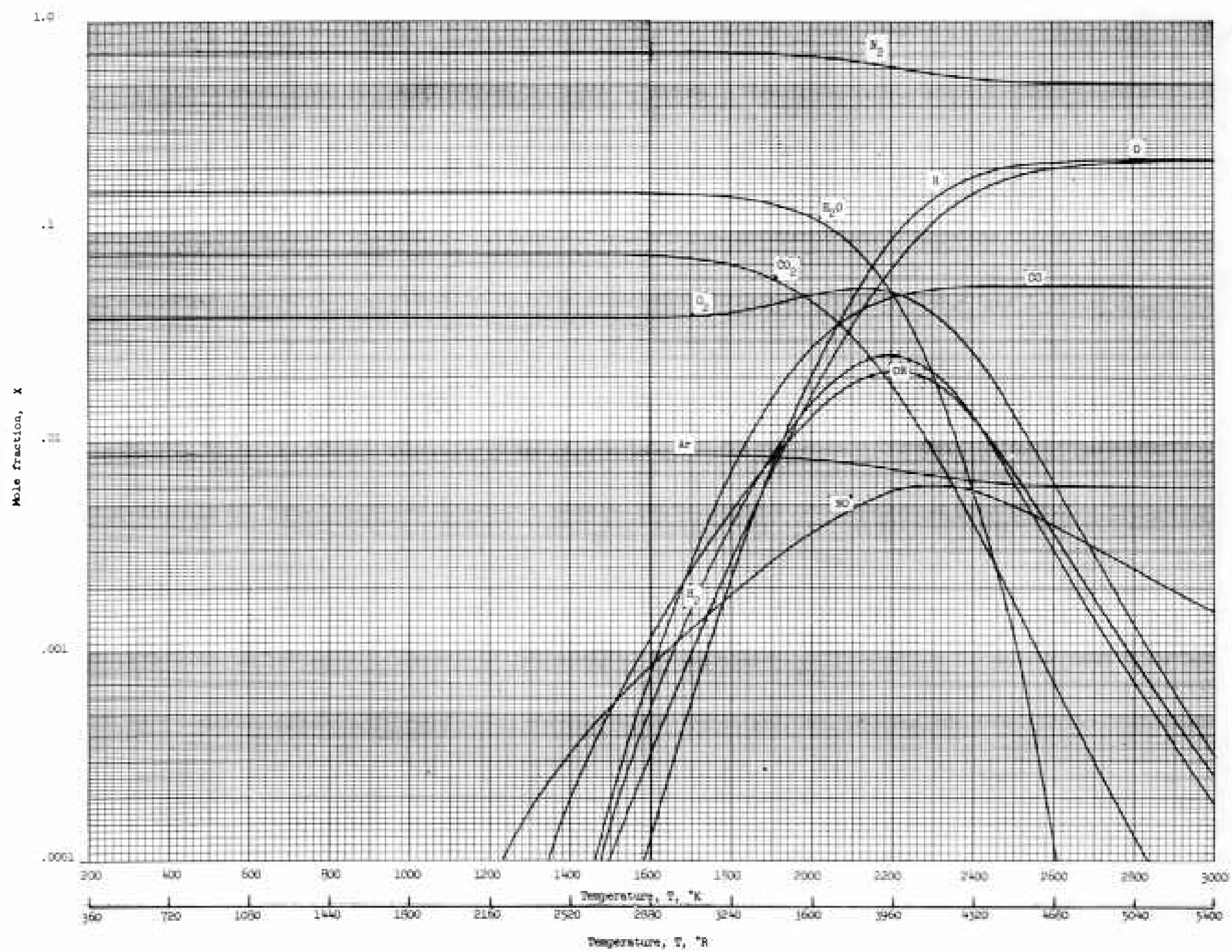
(b) $R_{eq} = 1.0$; $p = 0.01$ atmosphere.

Figure 3.- Continued.



(c) $R_{eq} = 1.0$; $p = 1.0$ atmosphere.

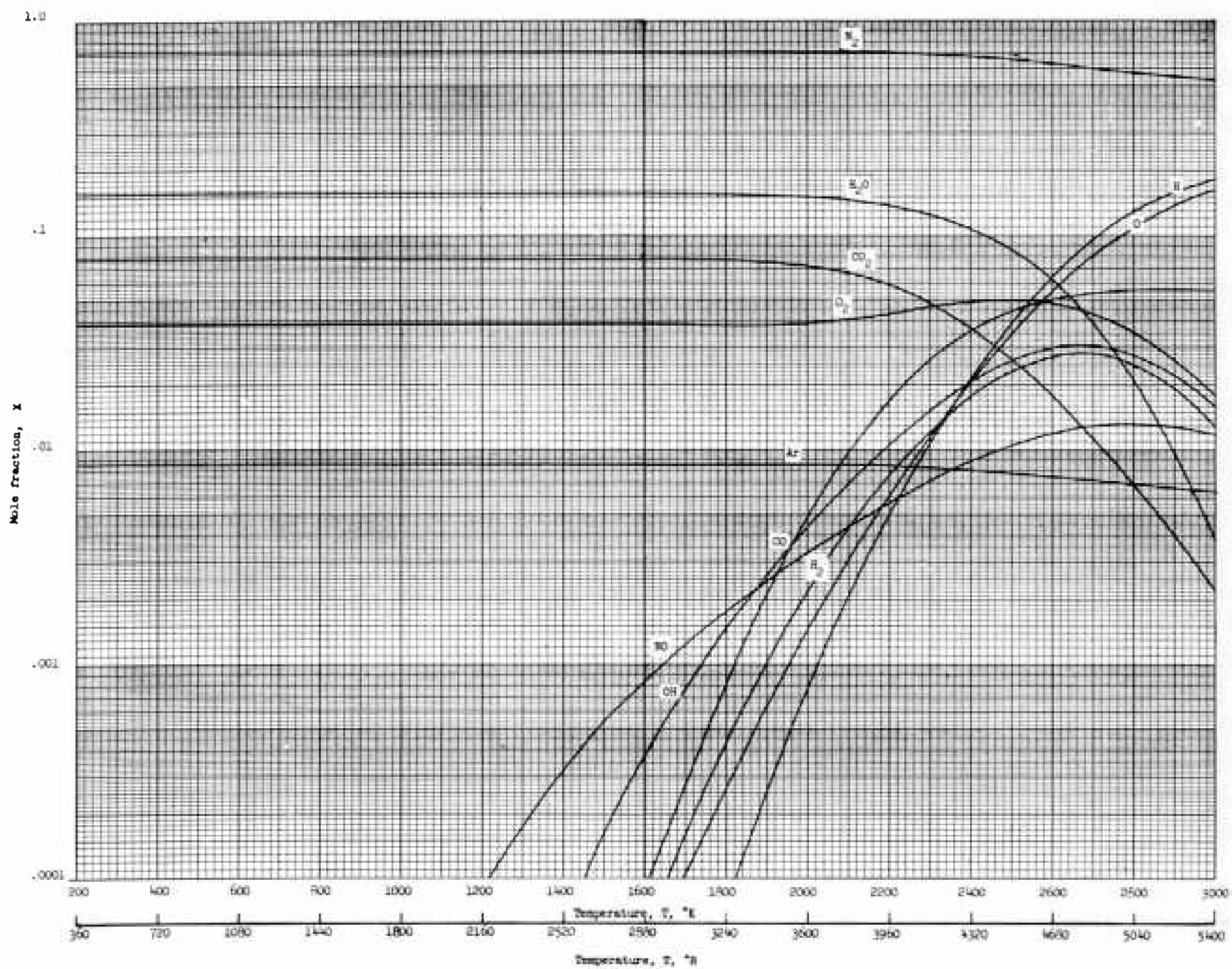
Figure 3.- Continued.



(d) $R_{eq} = 0.8$; $p = 0.0001$ atmosphere.

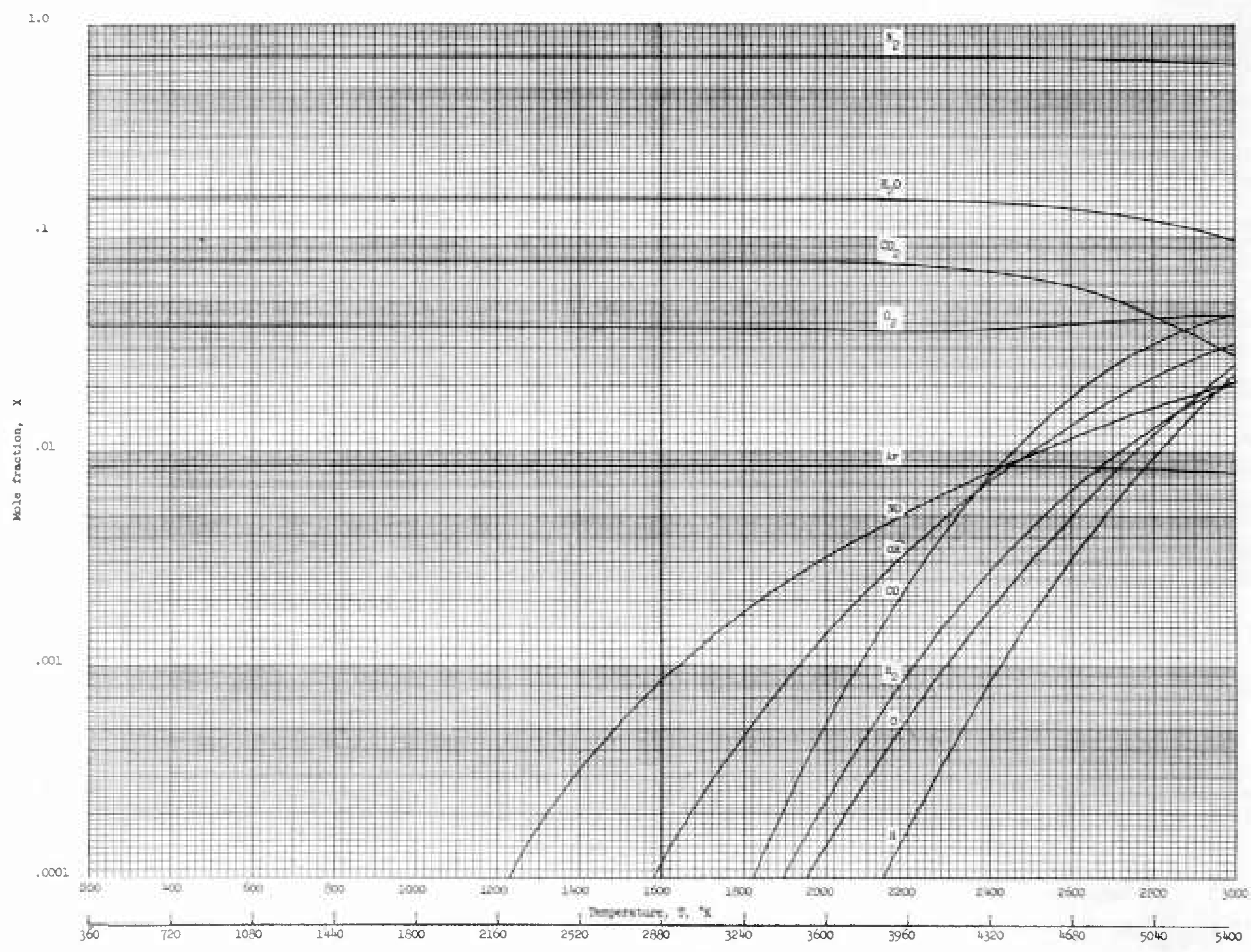
Figure 3.- Continued.

L-1396



(e) $R_{eq} = 0.8$; $p = 0.01$ atmosphere.

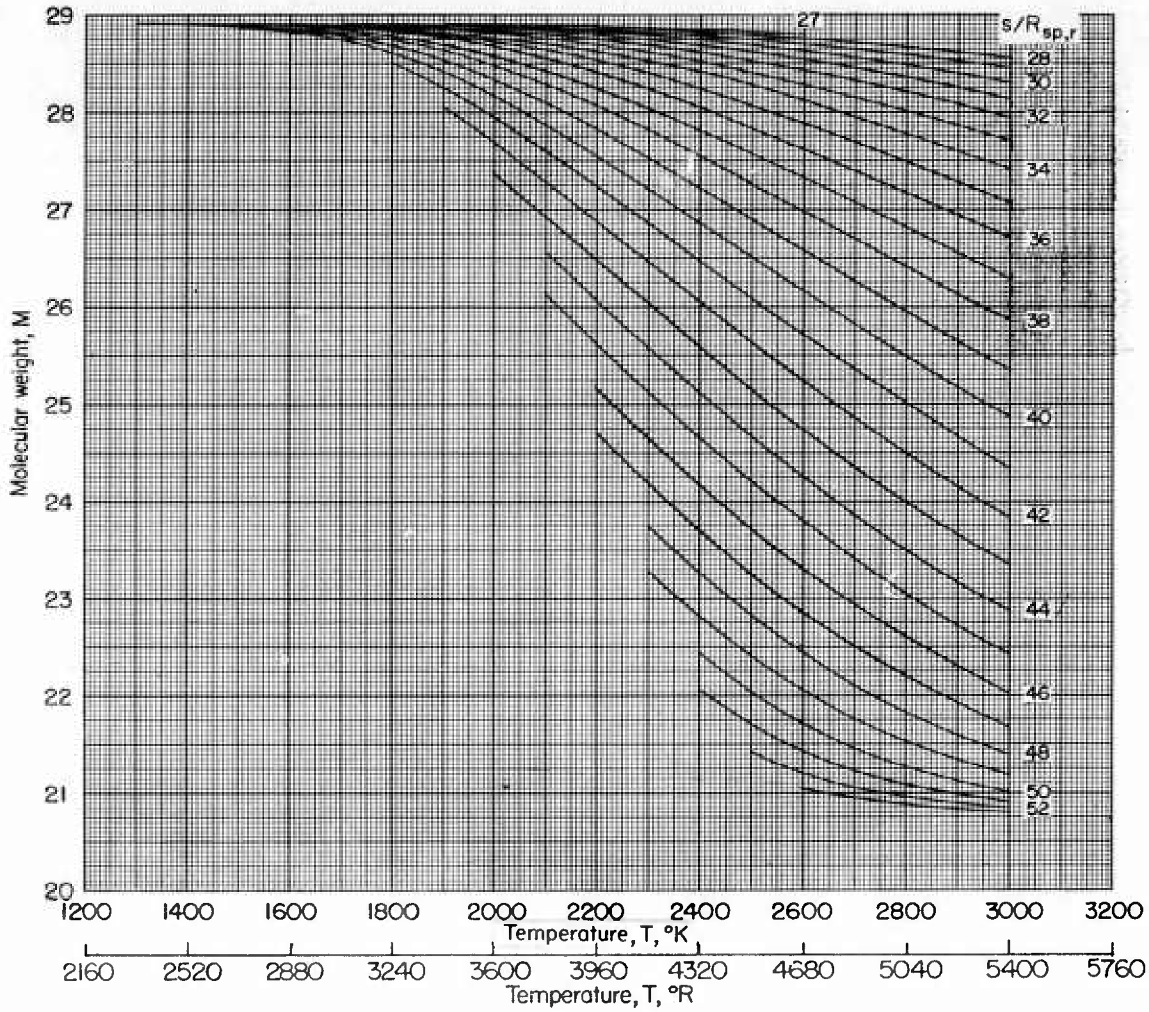
Figure 3.- Continued.



(f) $R_{eq} = 0.8$; $p = 1.0$ atmosphere.

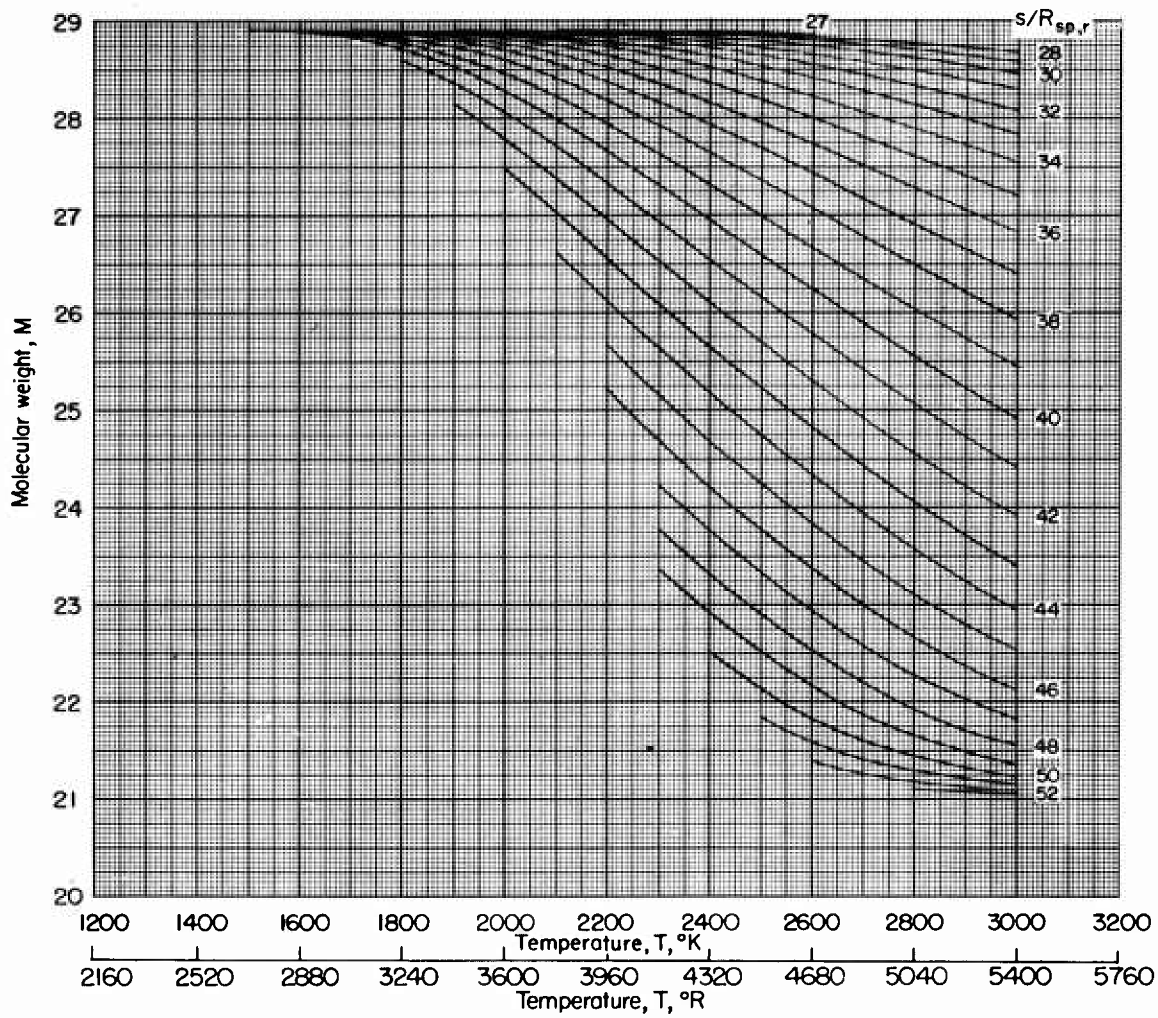
Figure 3.- Concluded.

L-1396



(a) $R_{eq} = 1.0$; $R_{sp,r} = 0.068700$.

Figure 4.- Molecular weight for C_2H_4-air combustion products against temperature for constant entropy.

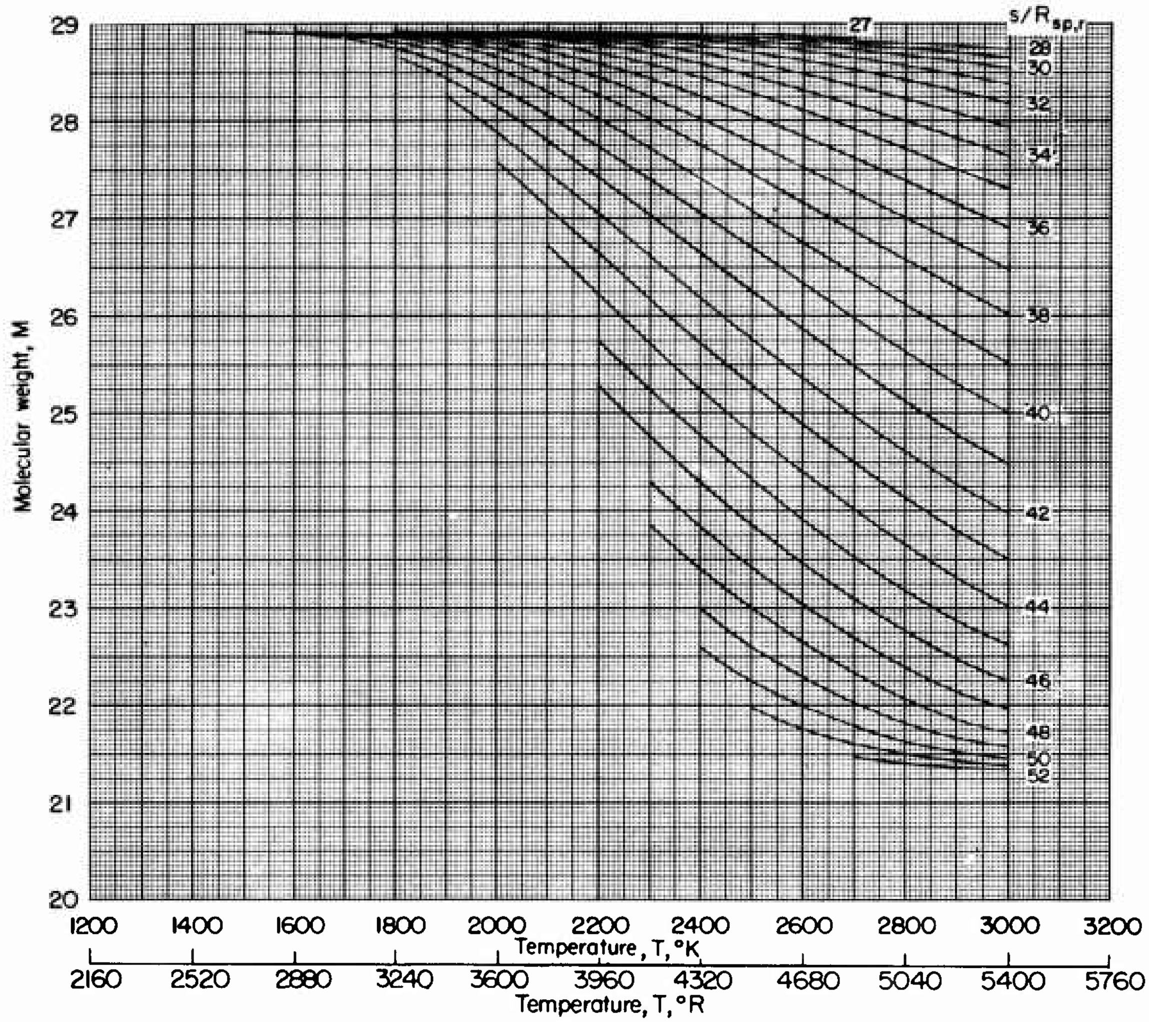


(b) $R_{eq} = 0.9$; $R_{sp,r} = 0.068687$.

Figure 4.- Continued.

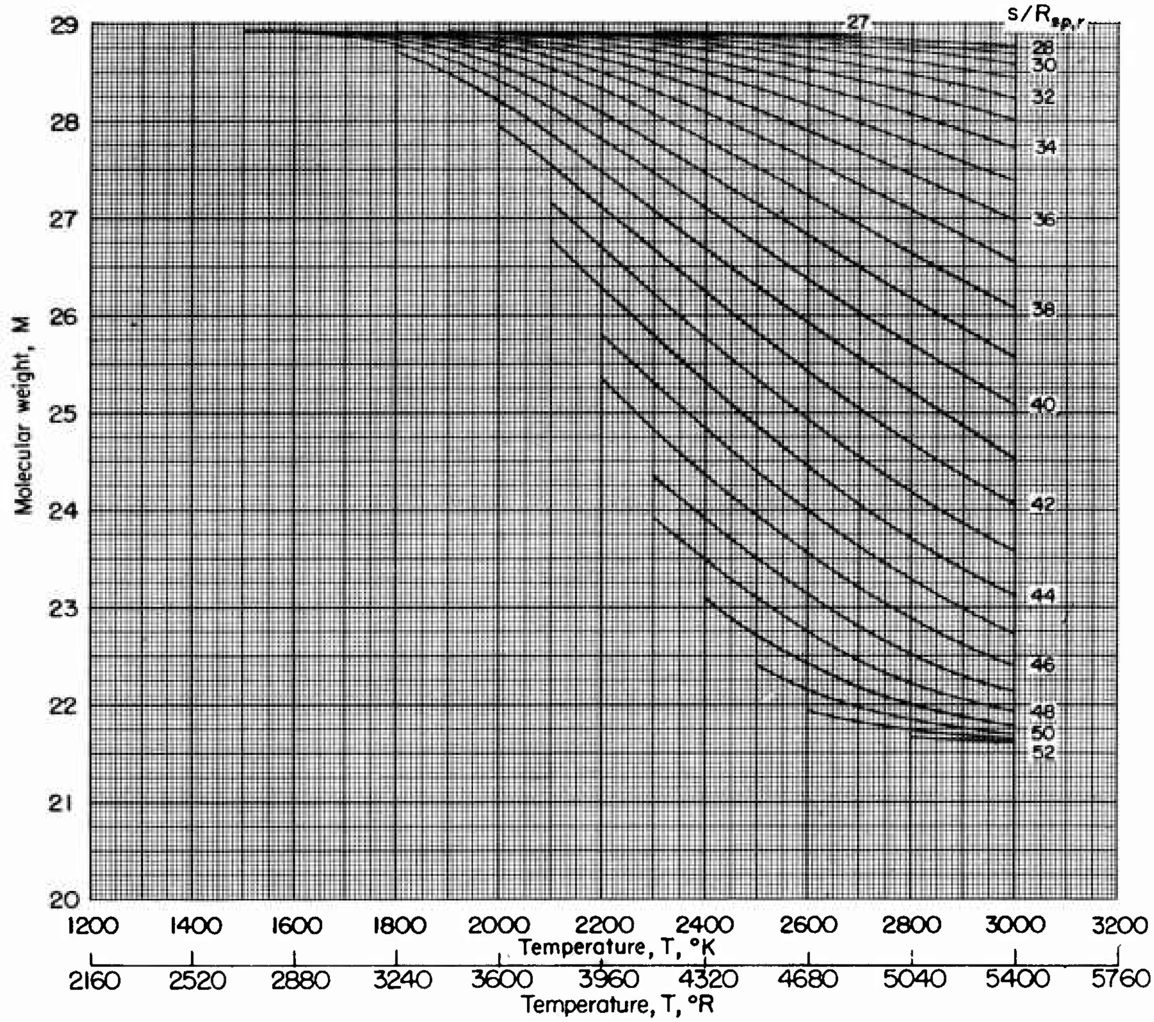
L-1396

L-1396



(c) $R_{eq} = 0.8$; $R_{sp,r} = 0.068673$.

Figure 4.- Continued.

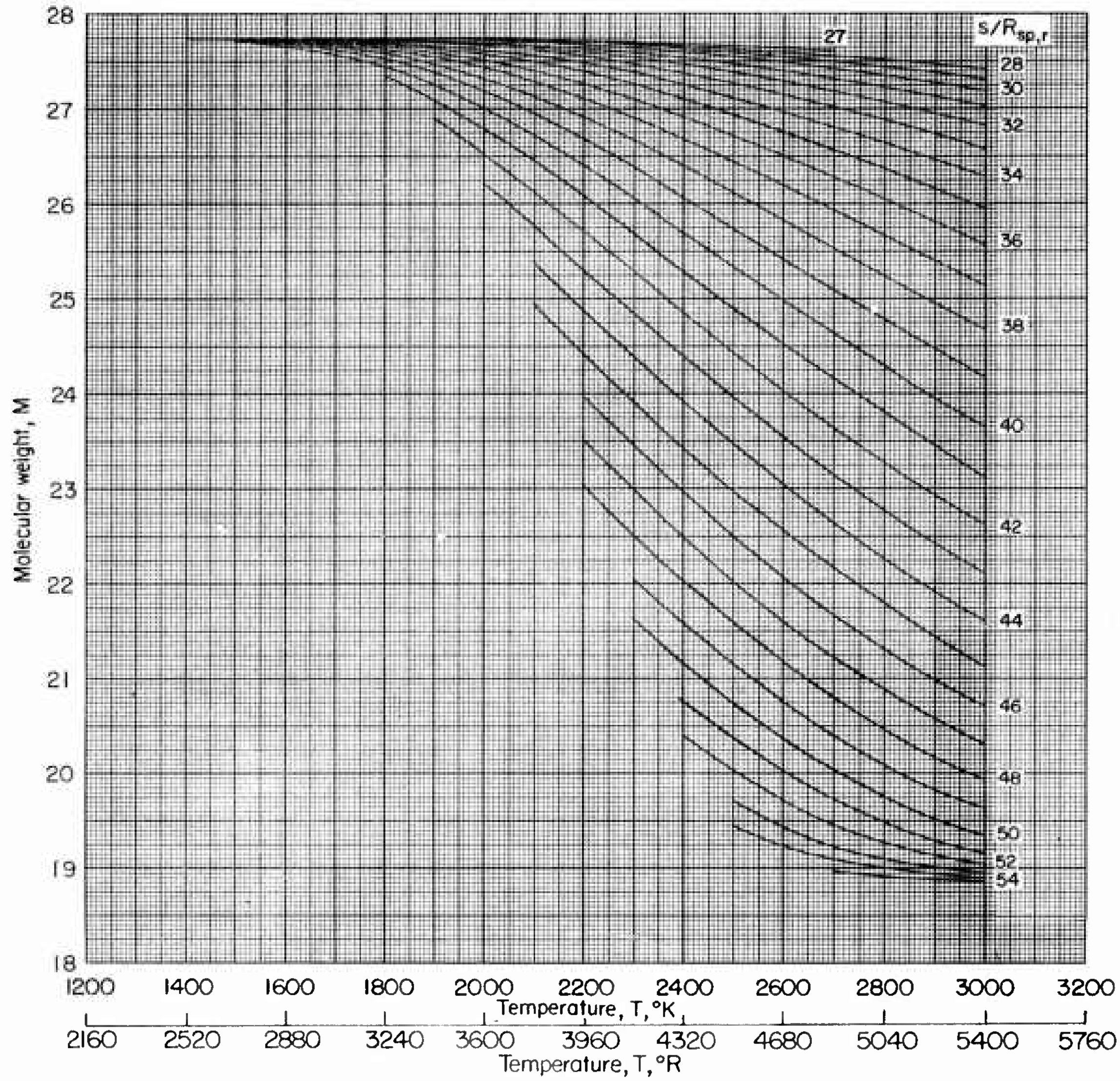


(d) $R_{eq} = 0.7$; $R_{sp,r} = 0.068659$.

Figure 4.- Concluded.

L-1396

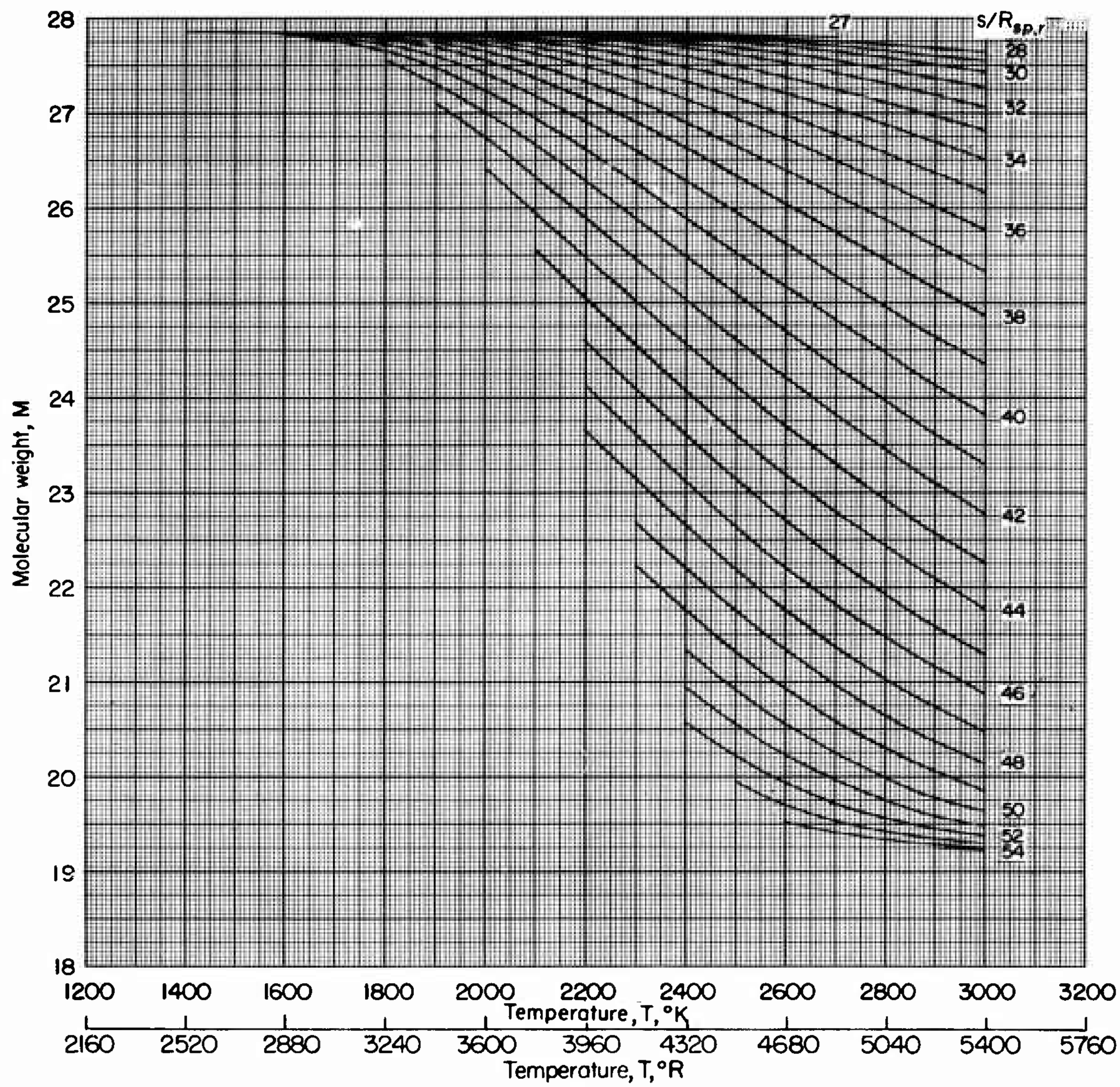
L-1396



(a) $R_{eq} = 1.0$; $R_{sp,r} = 0.071587$.

Figure 5.- Molecular weight for CH_4-air combustion products against temperature for constant entropy.

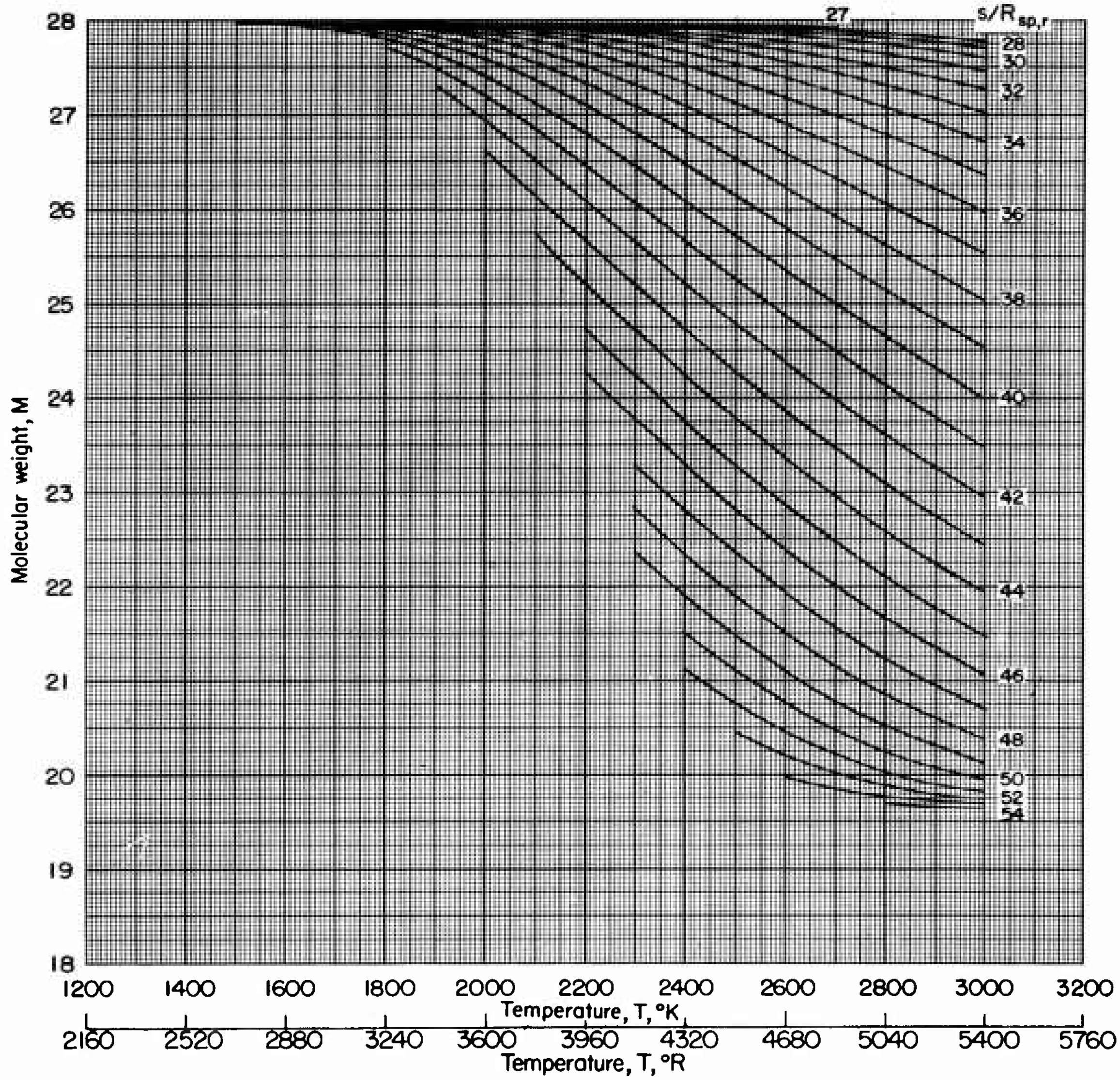
L-1396



(b) $R_{eq} = 0.9$; $R_{sp,r} = 0.071300$.

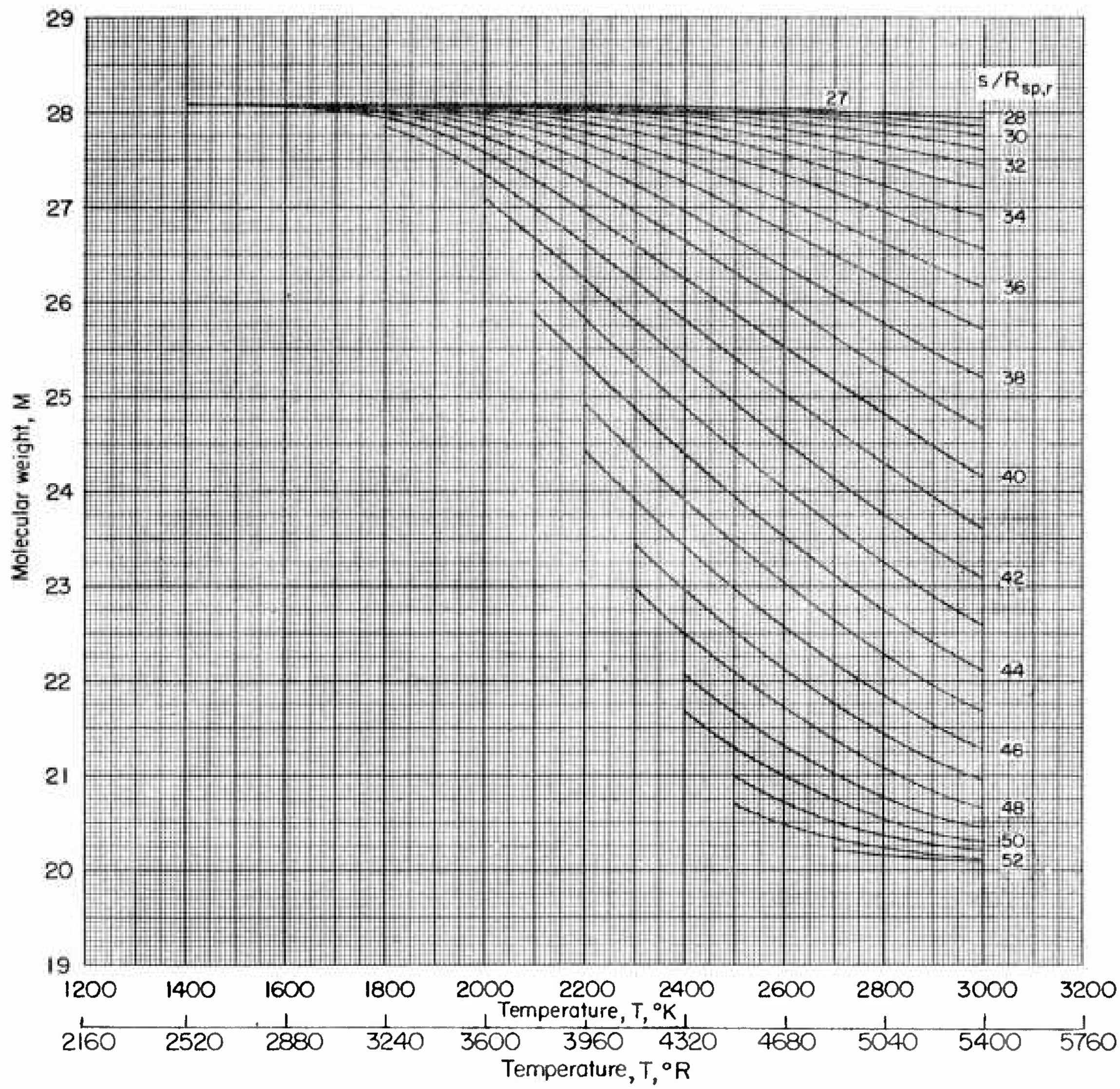
Figure 5.- Continued.

L-1396



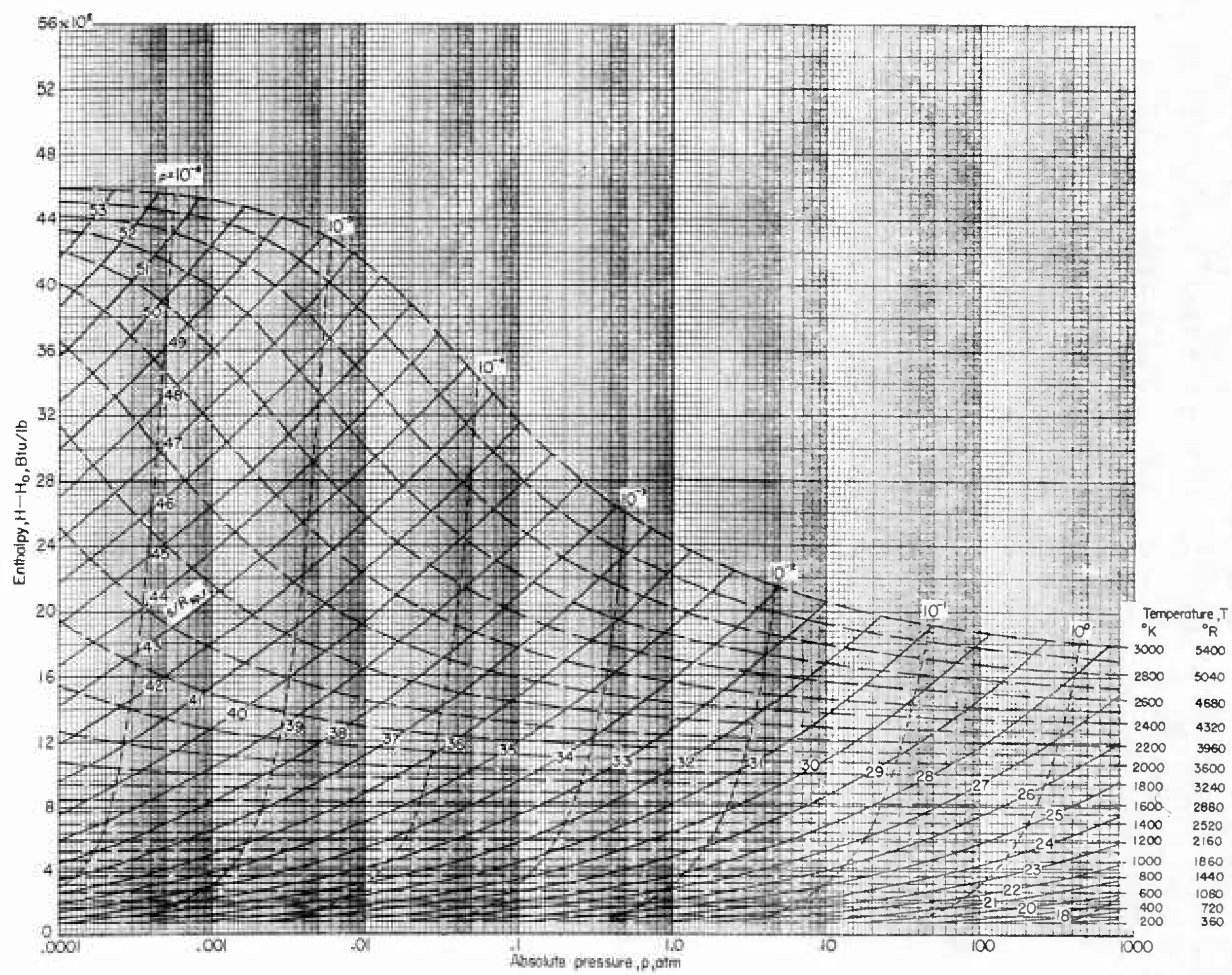
(c) $R_{eq} = 0.8$; $R_{sp,r} = 0.071008$.

Figure 5.- Continued.



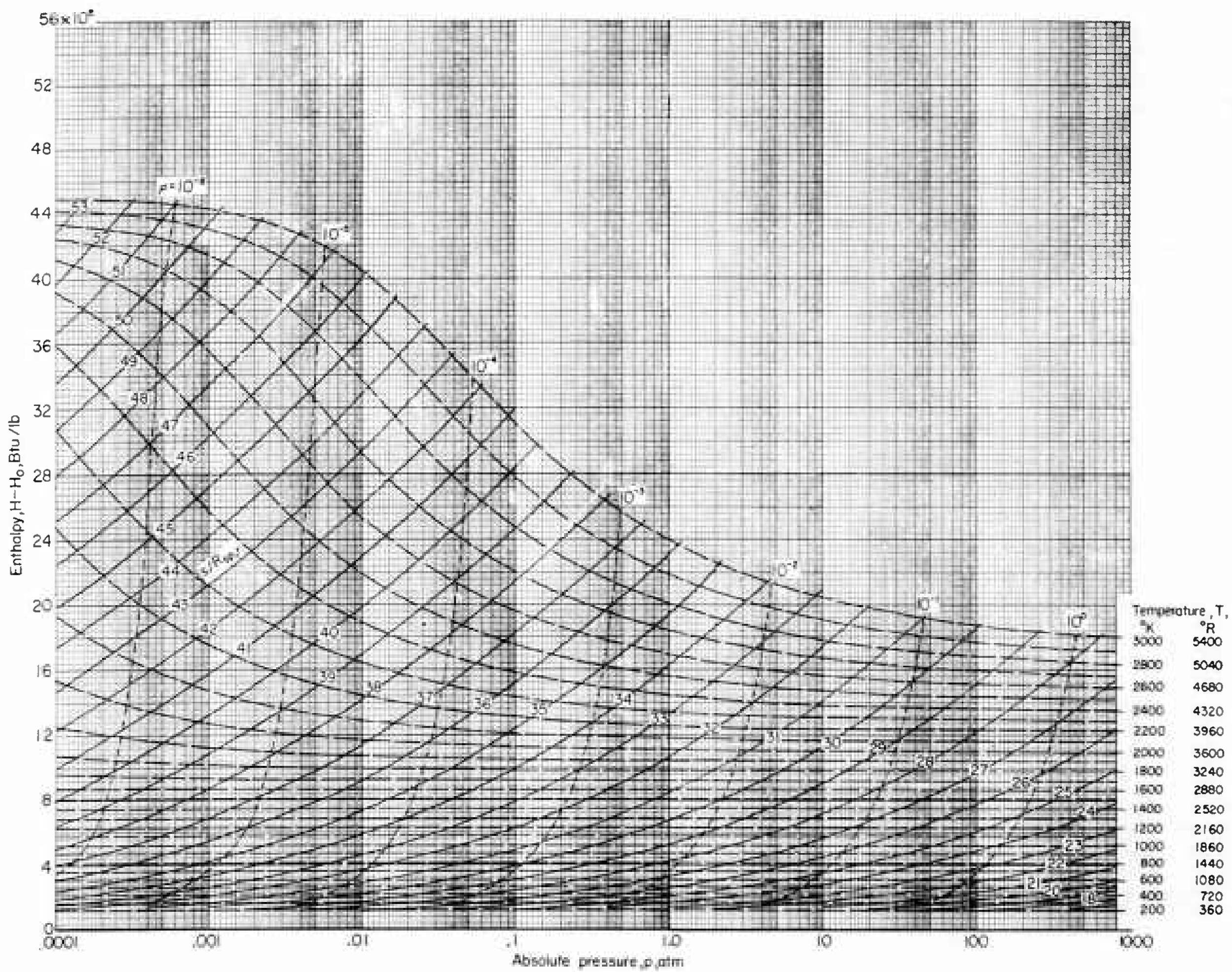
(d) $R_{eq} = 0.7$; $R_{sp,r} = 0.070714$.

Figure 5.- Concluded.



(a) $R_{eq} = 1.0$; $R_{sp,r} = 0.068700$.

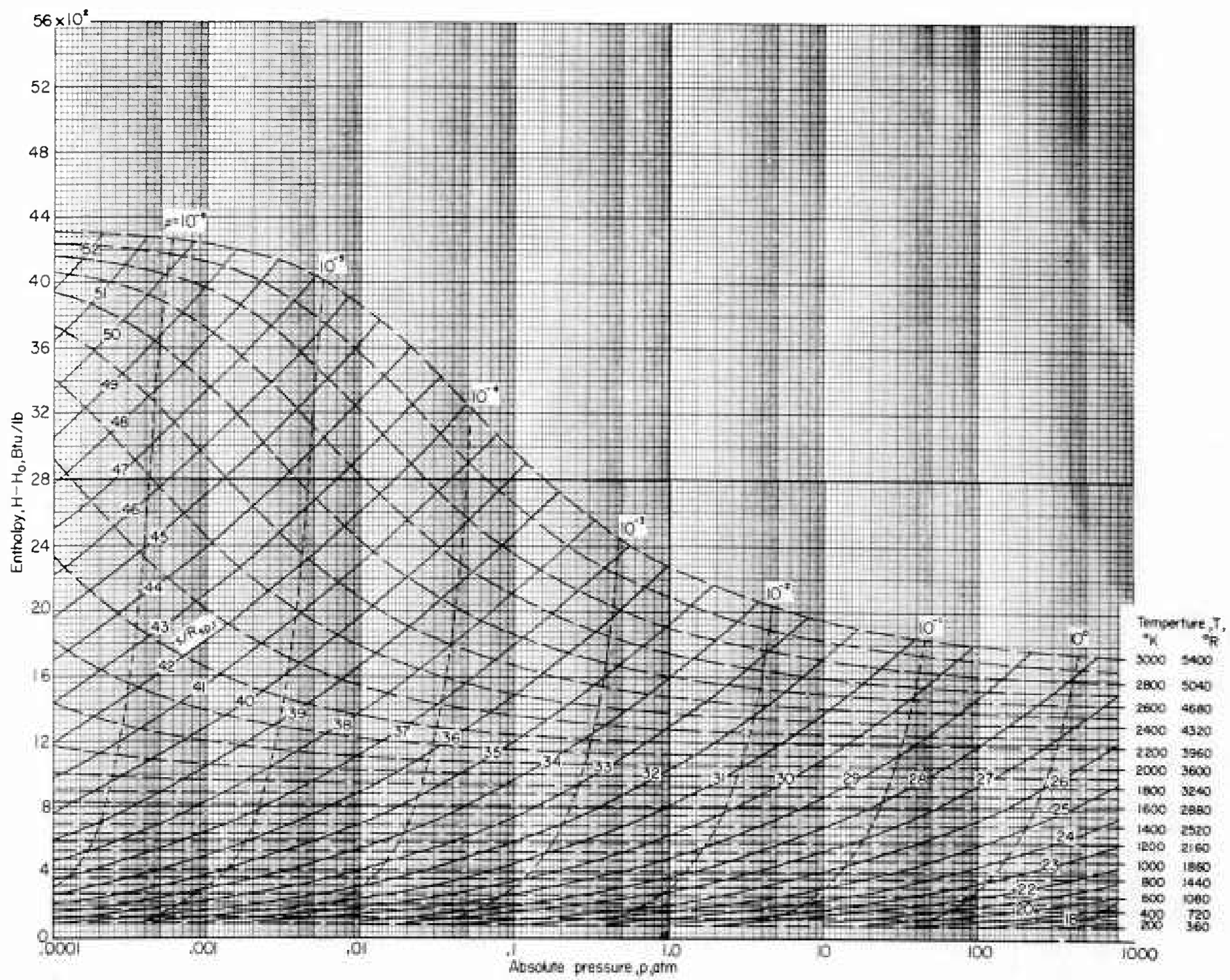
Figure 6.- Thermodynamic chart for C_2H_4-air combustion products.



(b) $R_{eq} = 0.9$; $R_{sp,r} = 0.068687$.

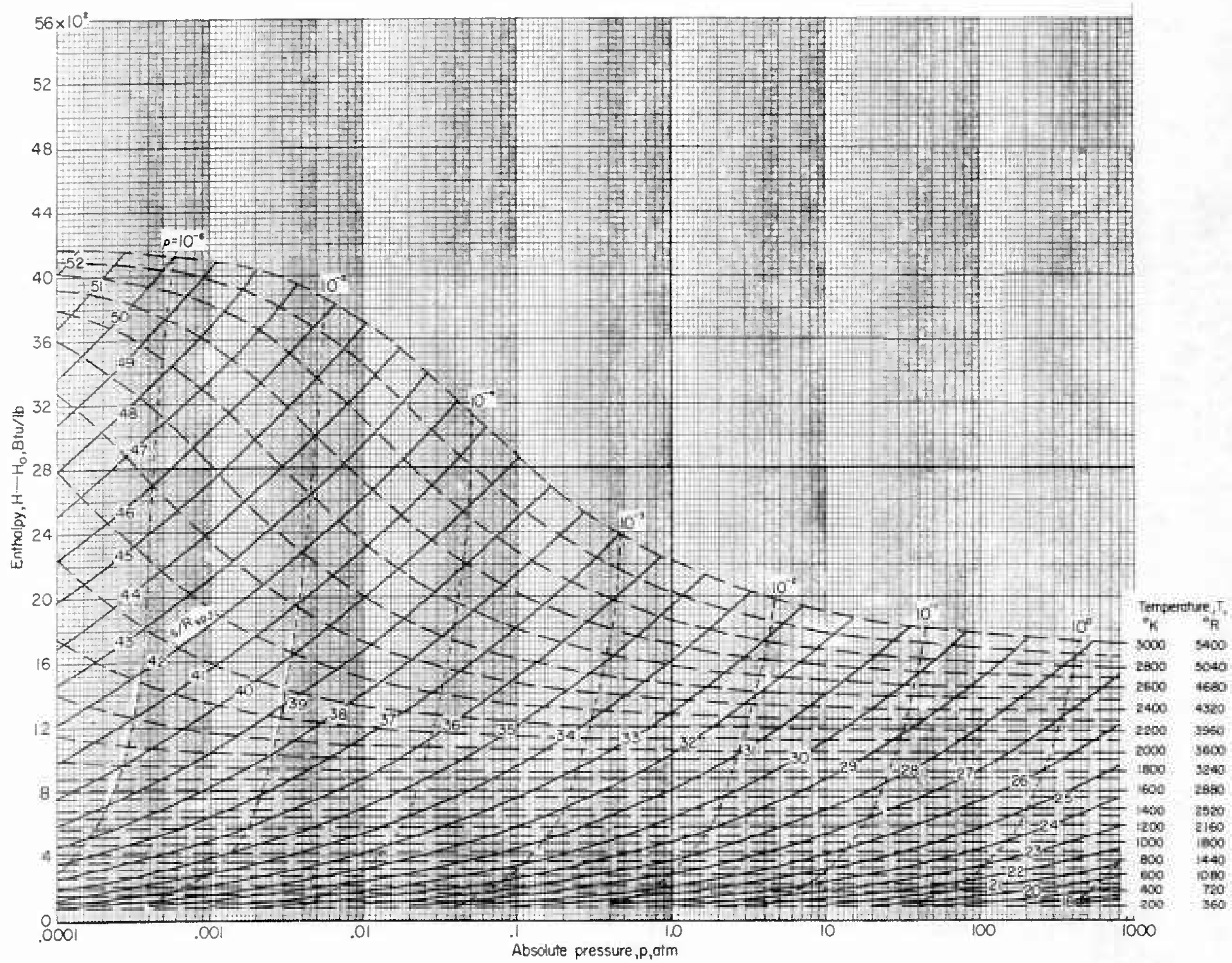
Figure 6.- Continued.

L-1396



(c) $R_{eq} = 0.8$; $R_{sp,r} = 0.068673$.

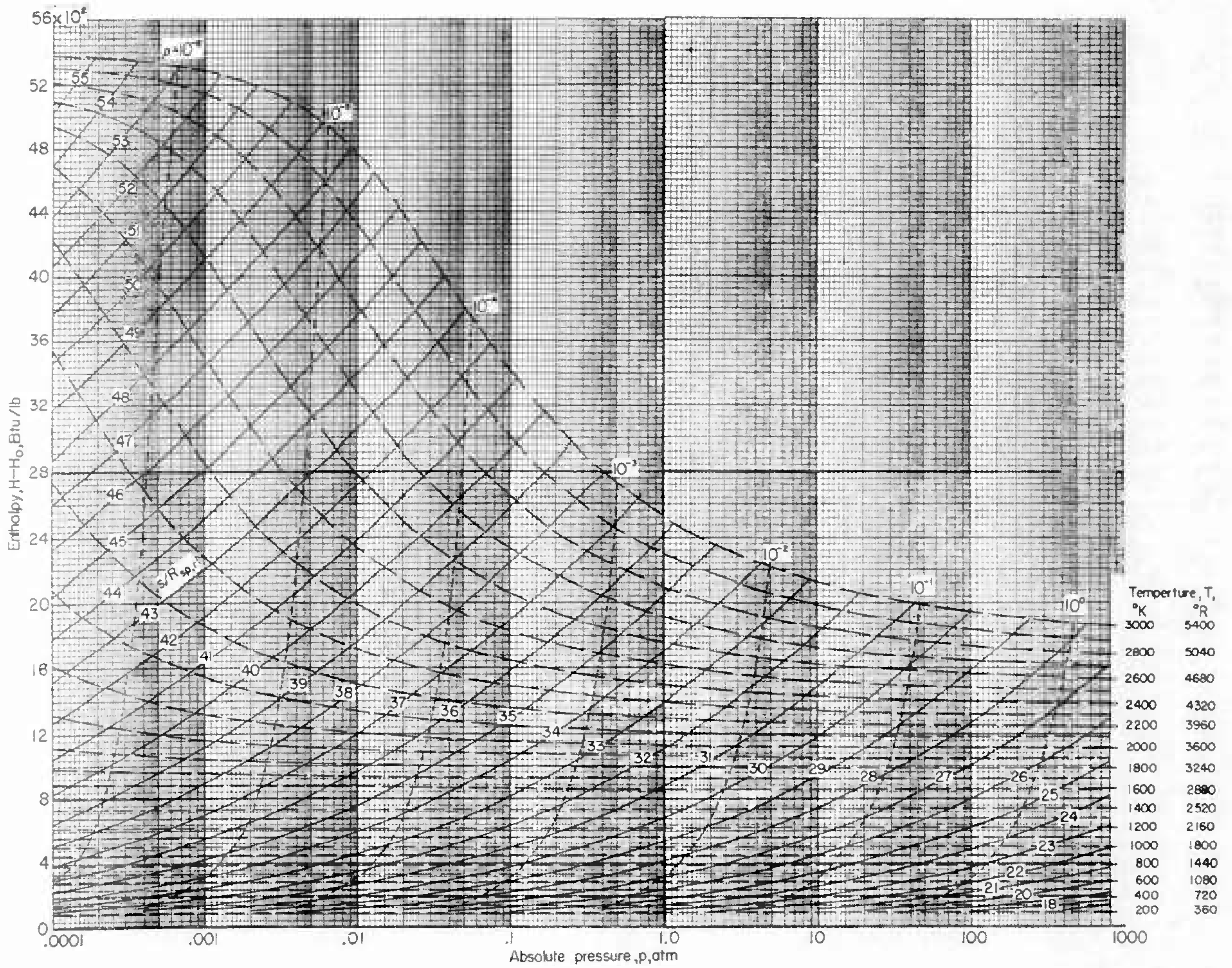
Figure 6.- Continued.



(d) $R_{eq} = 0.7$; $R_{sp,r} = 0.068659$.

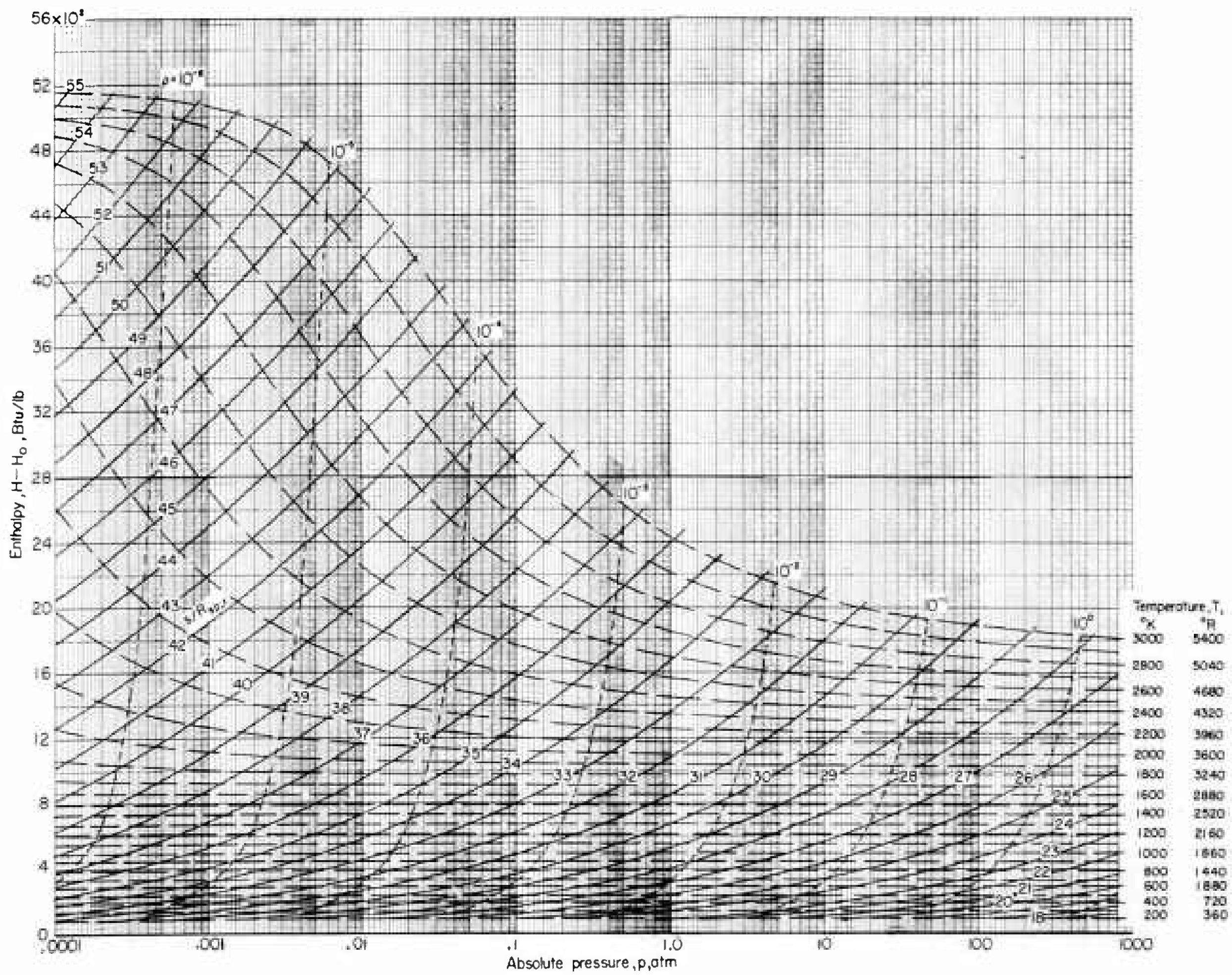
Figure 6.- Concluded.

L-1396



(a) $R_{eq} = 1.0$; $R_{sp,r} = 0.071587$.

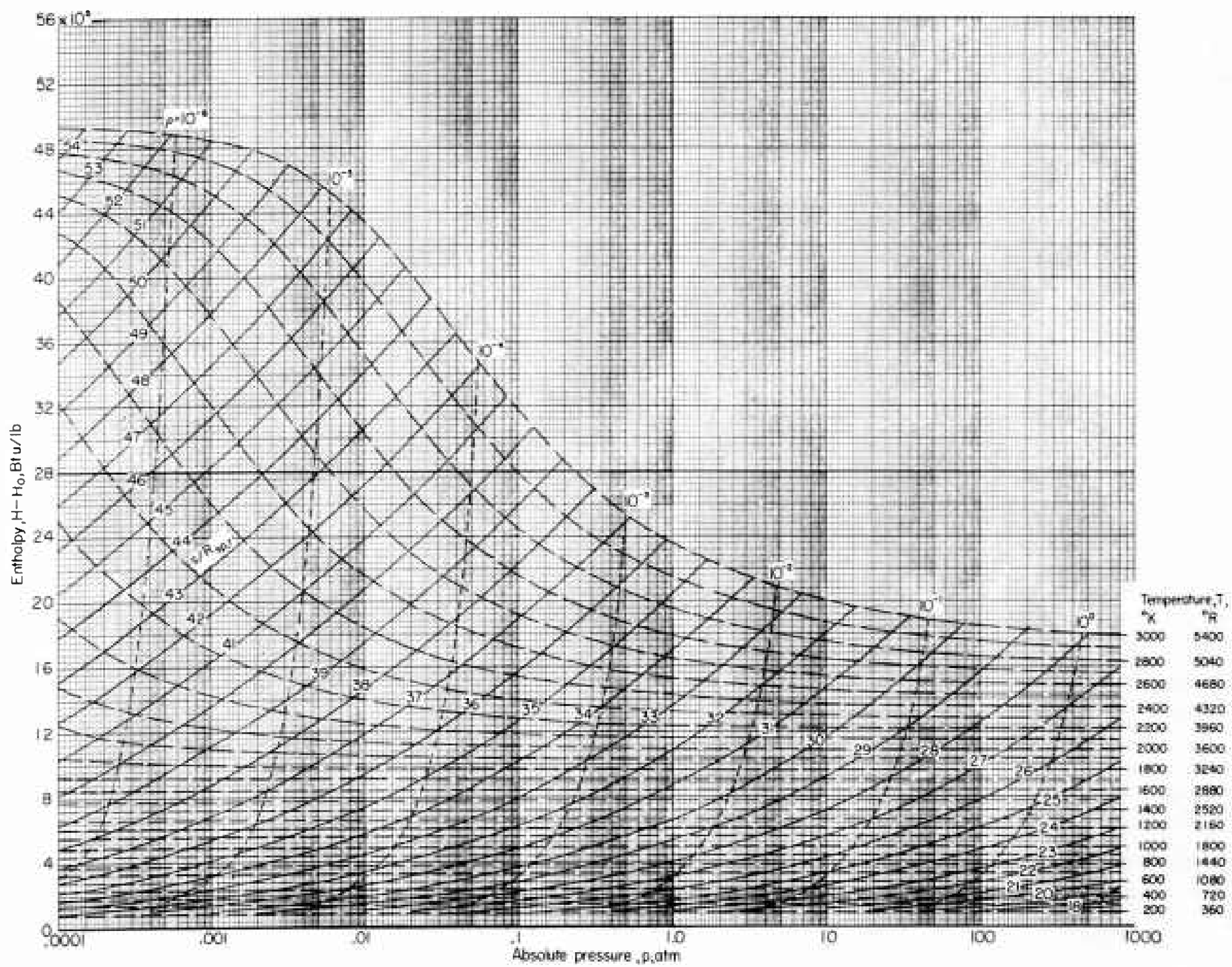
Figure 7.- Thermodynamic chart for CH_4-air combustion products.



(b) $R_{eq} = 0.9$; $R_{sp,r} = 0.071300$.

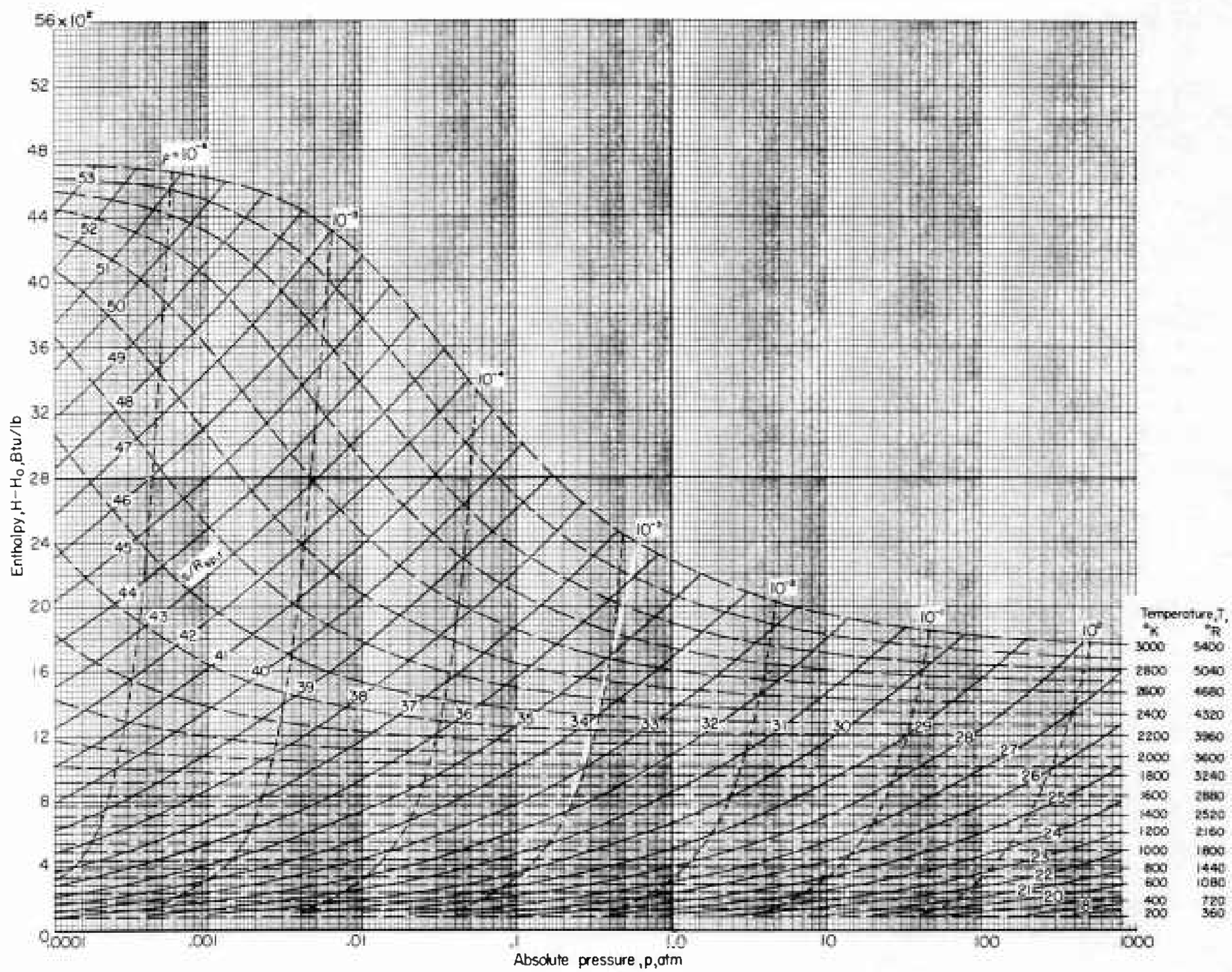
Figure 7.- Continued.

L-1396



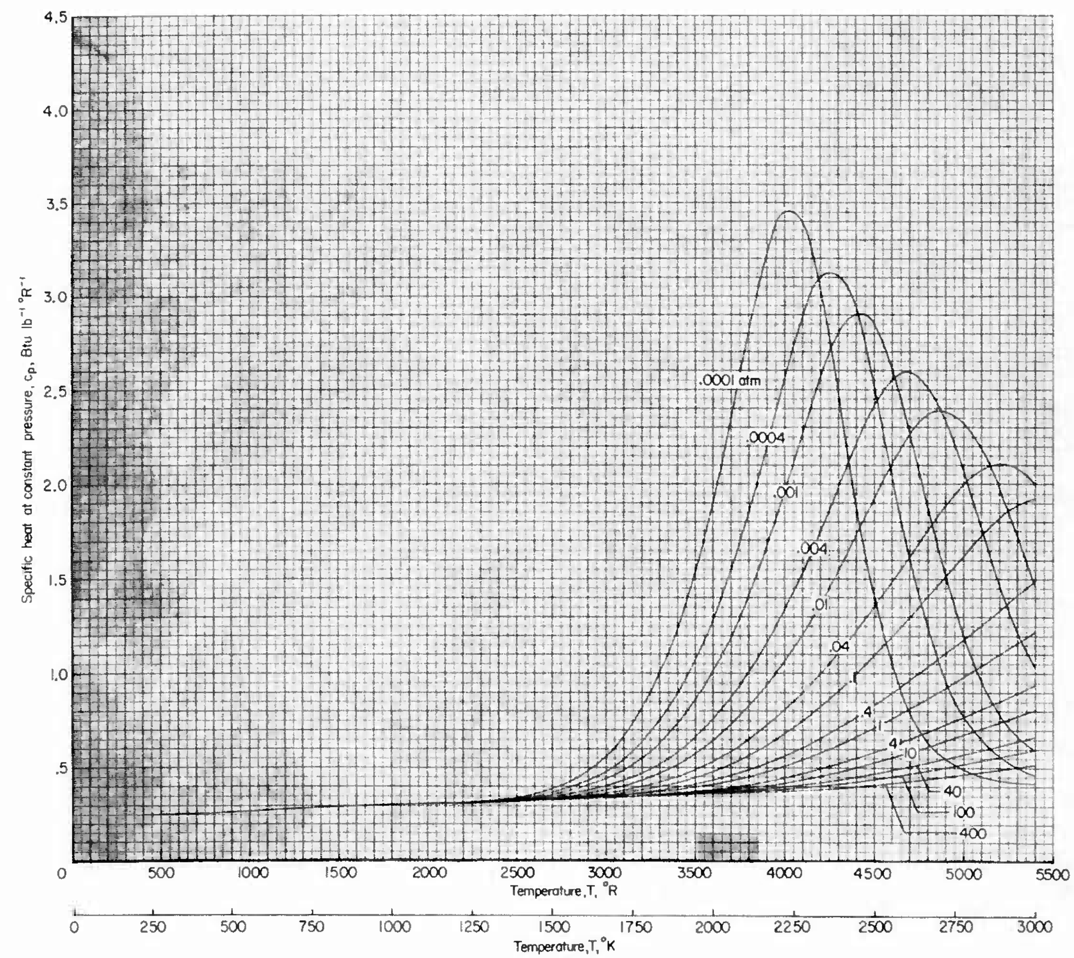
(c) $R_{eq} = 0.8$; $R_{sp,r} = 0.071008$.

Figure 7.- Continued.



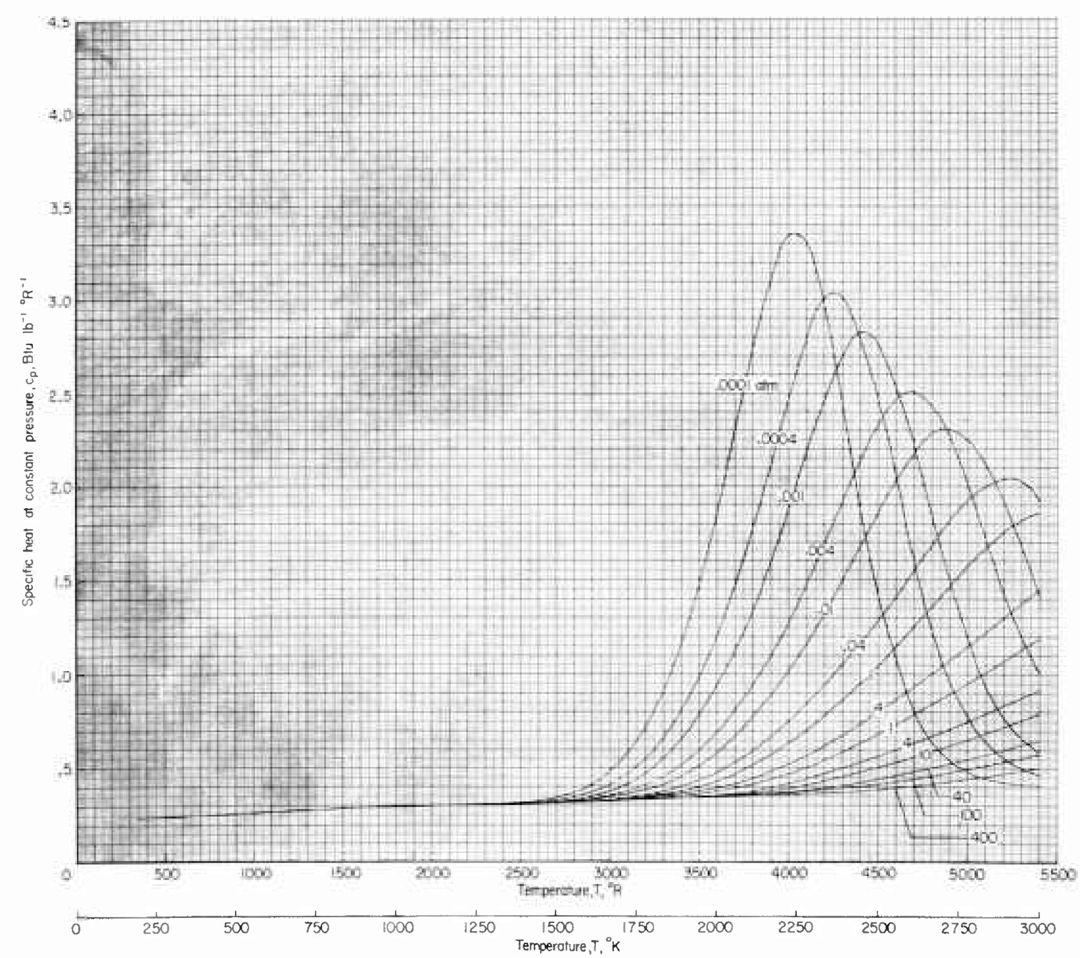
(d) $R_{eq} = 0.7$; $R_{sp,r} = 0.070714$.

Figure 7.- Concluded.



(a) Equivalence ratio, 1.0.

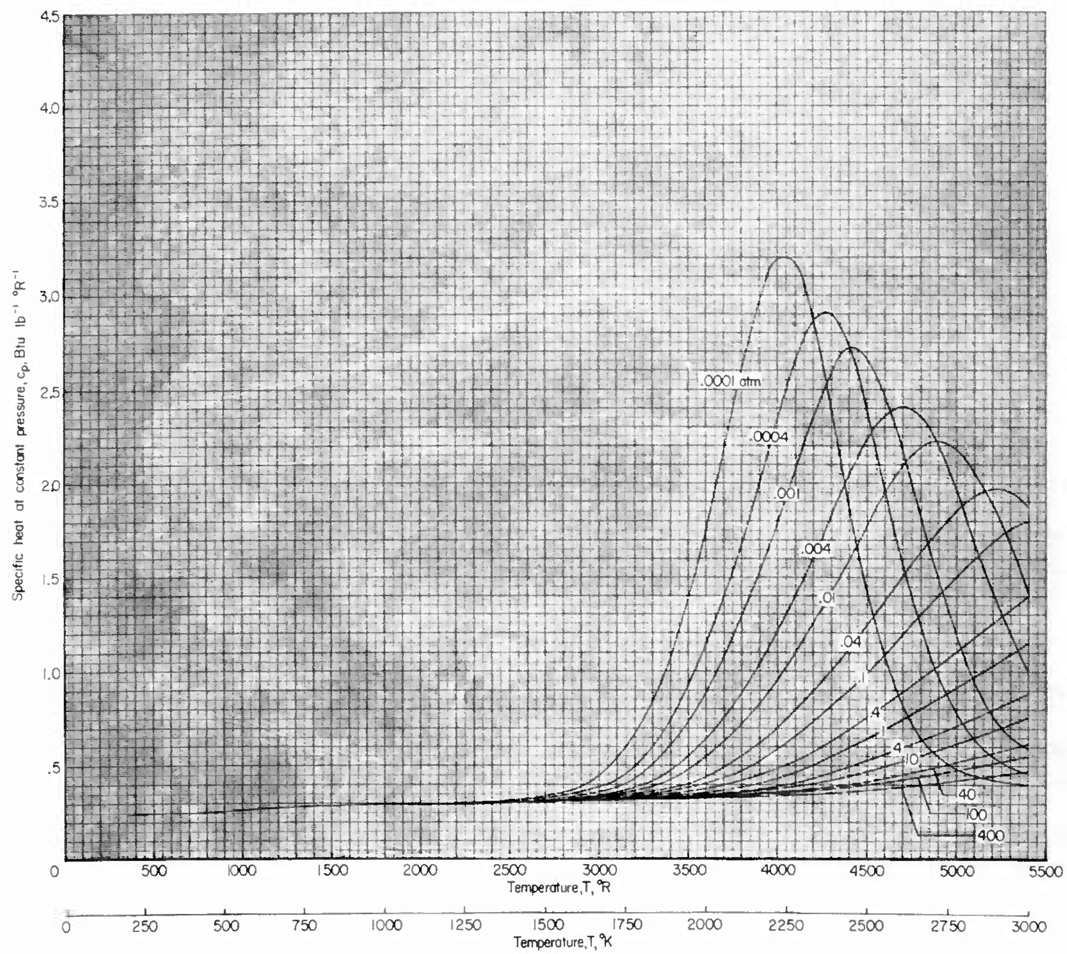
Figure 8.- Specific heat as a function of temperature for C_2H_4-air combustion products at various pressures and equivalence ratios.



(b) Equivalence ratio, 0.9.

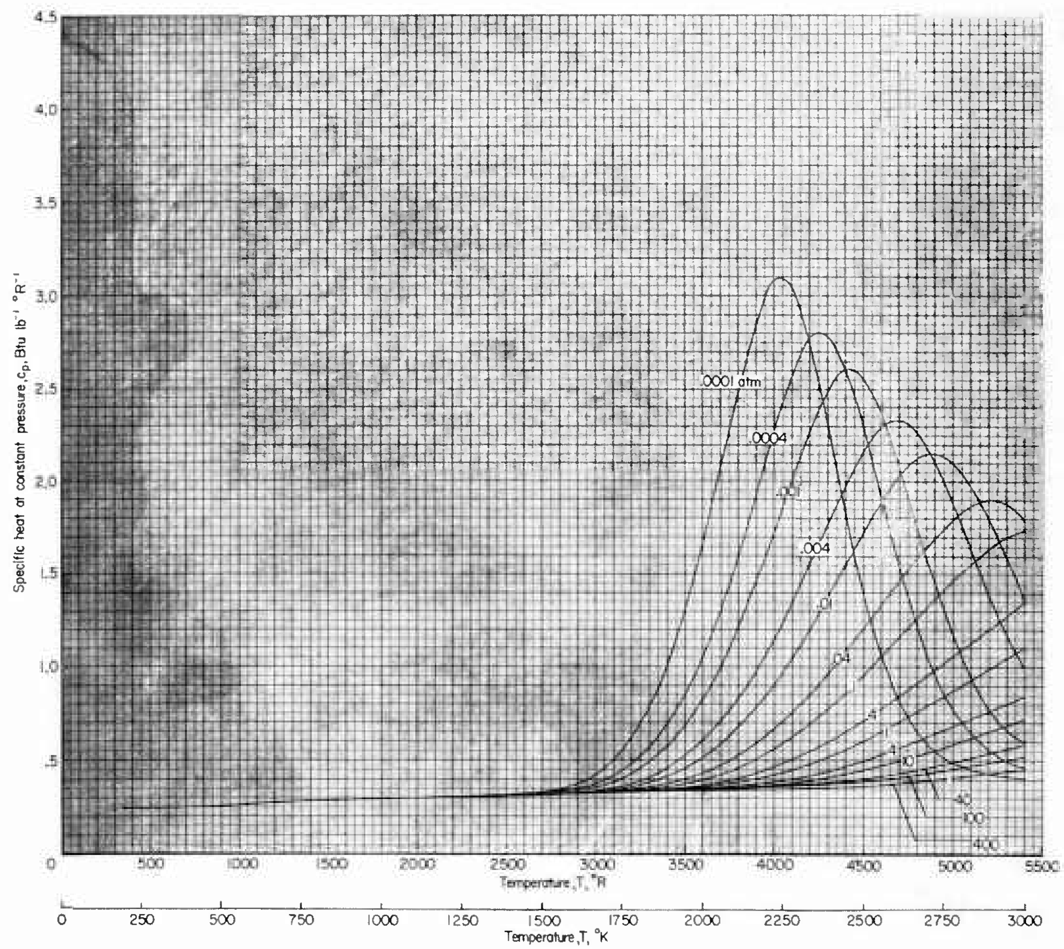
Figure 8.- Continued.

L-1396



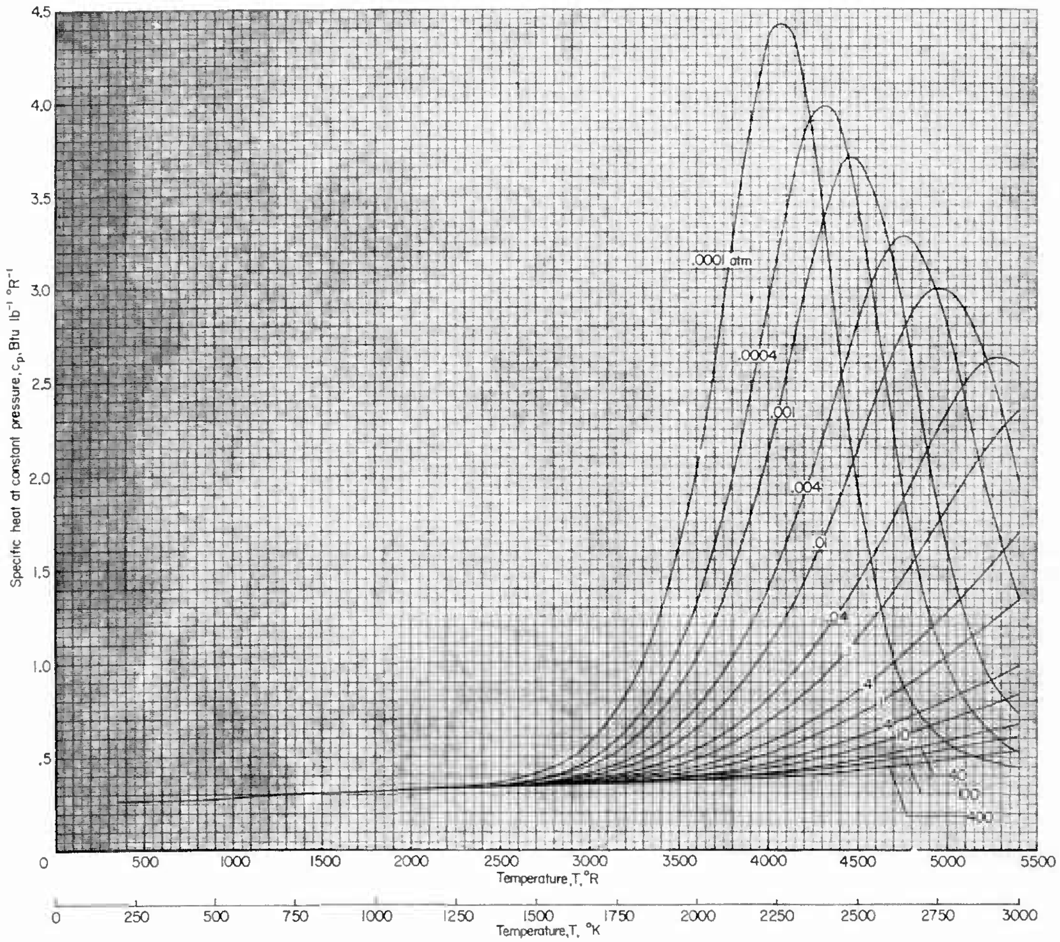
(c) Equivalence ratio, 0.8.

Figure 8.- Continued.



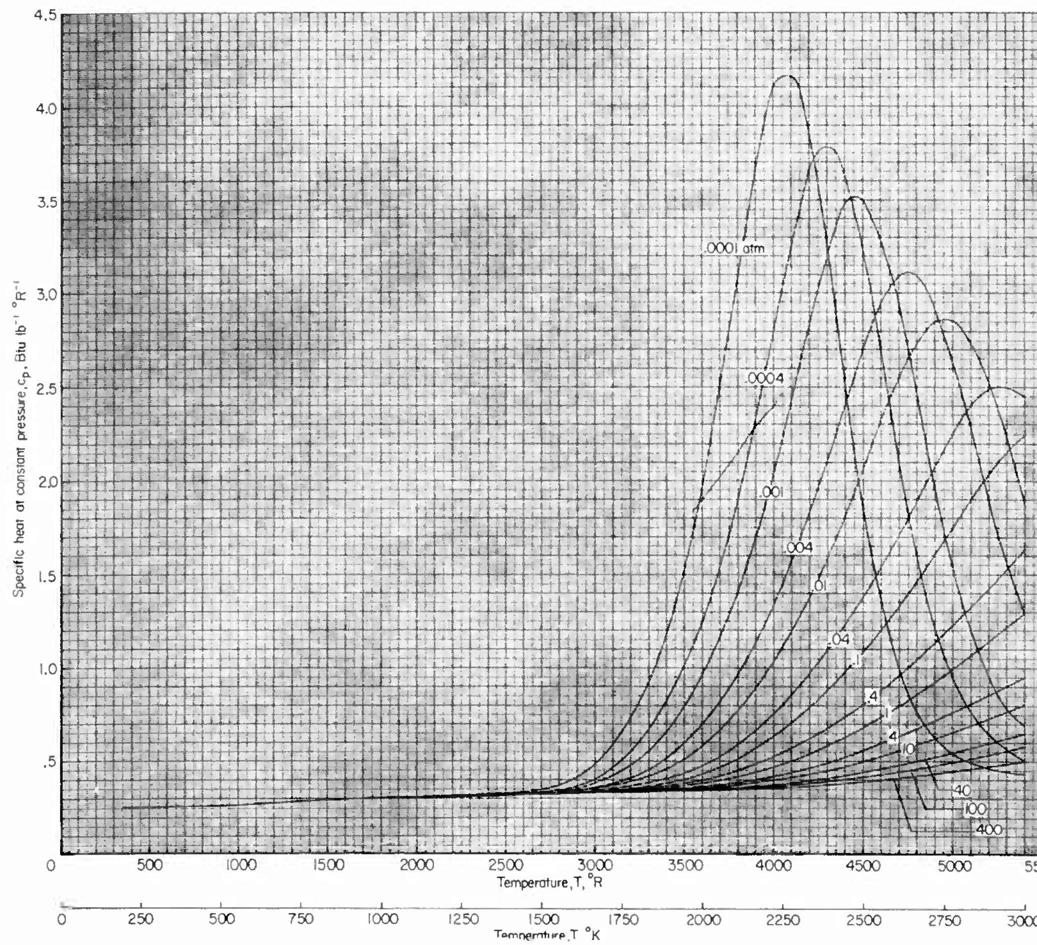
(d) Equivalence ratio, 0.7.

Figure 8.- Concluded.



(a) Equivalence ratio, 1.0.

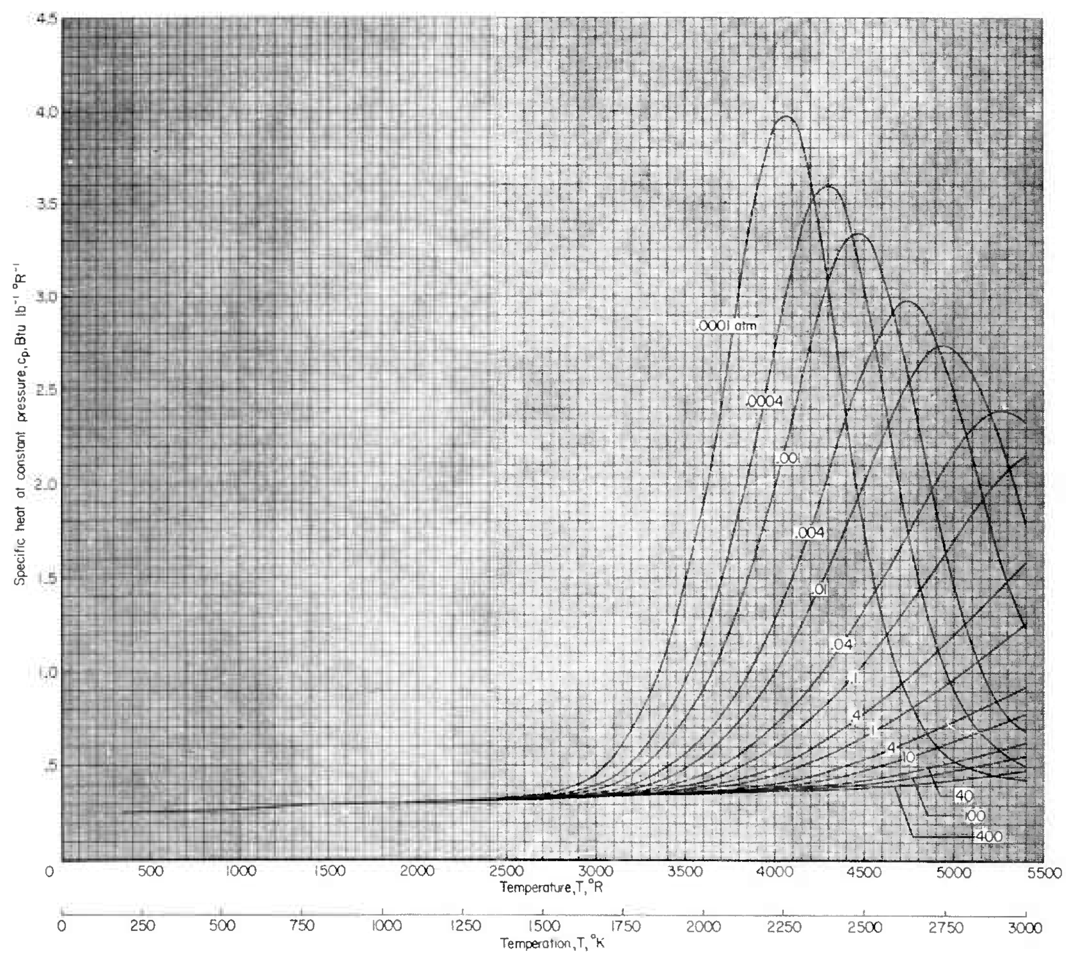
Figure 9.- Specific heat as a function of temperature for CH_4-air combustion products at various pressures and equivalence ratios.



(b) Equivalence ratio, 0.9.

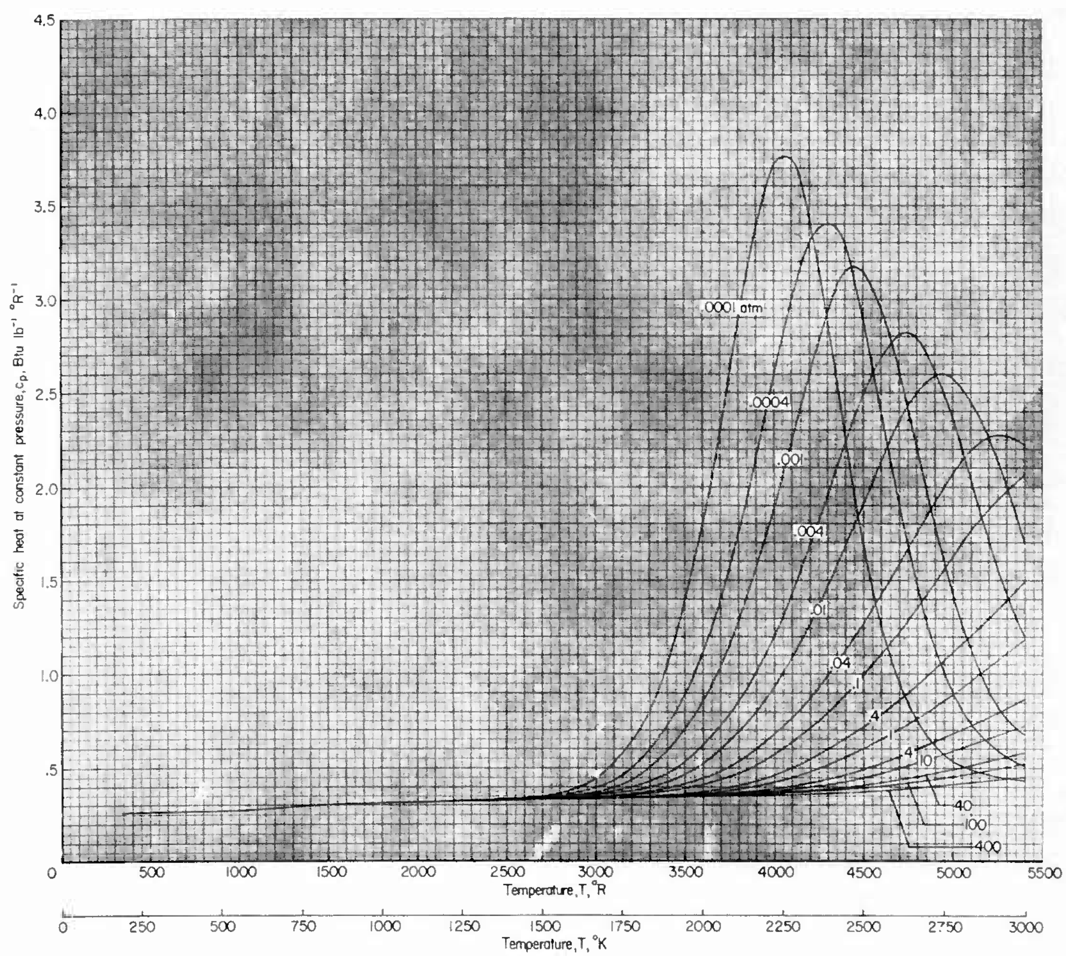
Figure 9.- Continued.

L-1396



(c) Equivalence ratio, 0.8.

Figure 9.- Continued.



(d) Equivalence ratio, 0.7.

Figure 9.- Concluded.

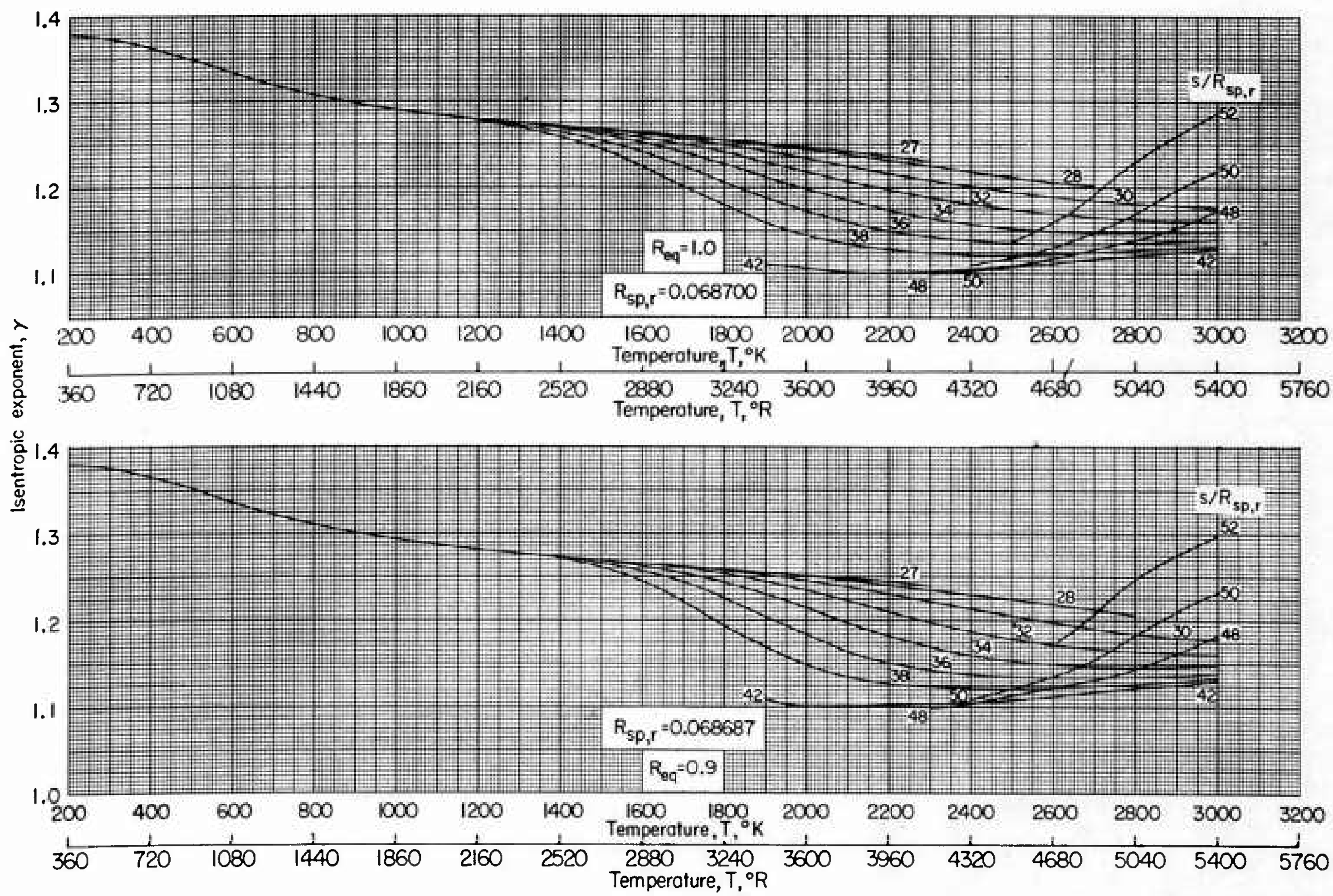


Figure 10.- Isentropic exponent for C_2H_4-air combustion products against temperature for constant entropy.

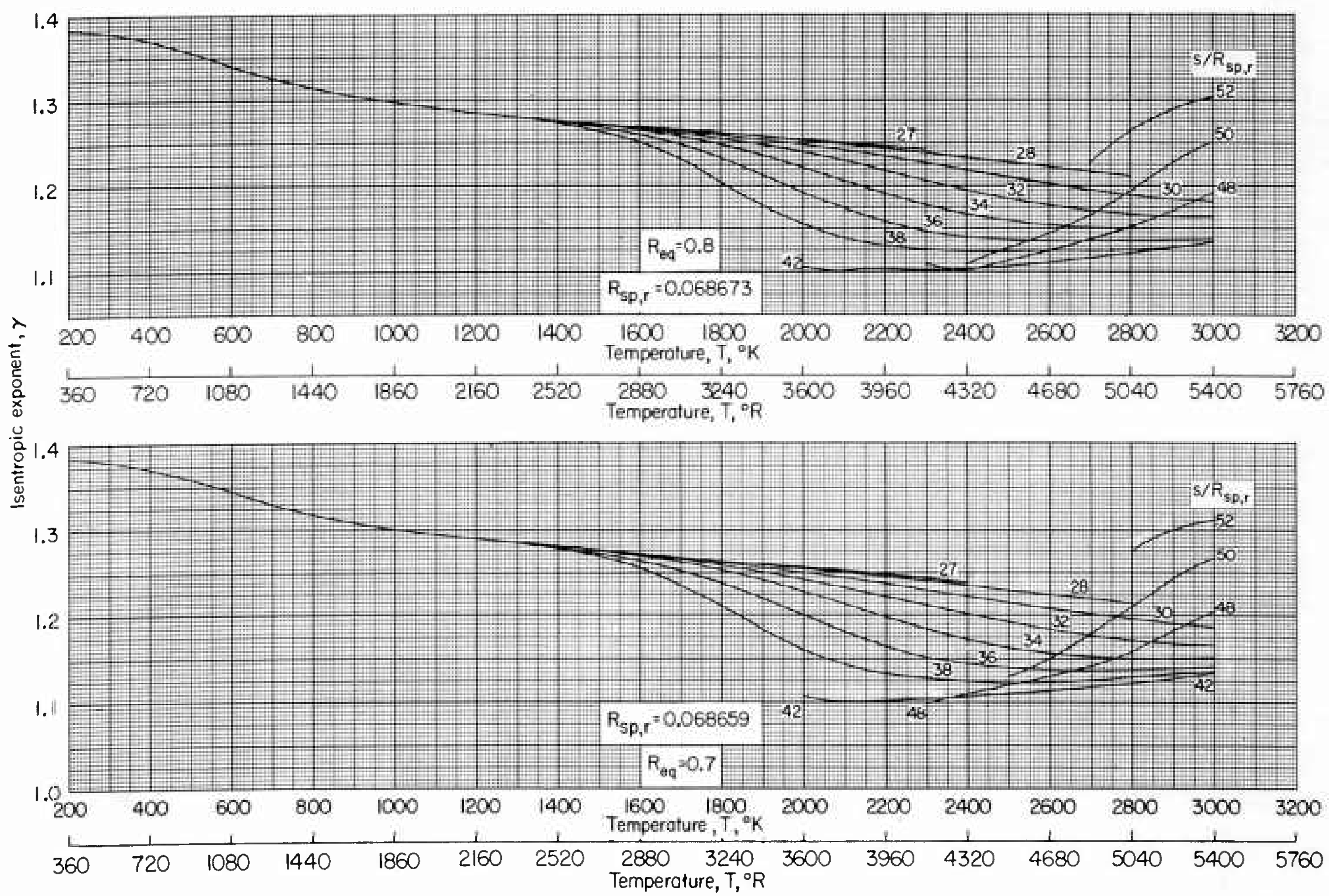


Figure 10.- Concluded.

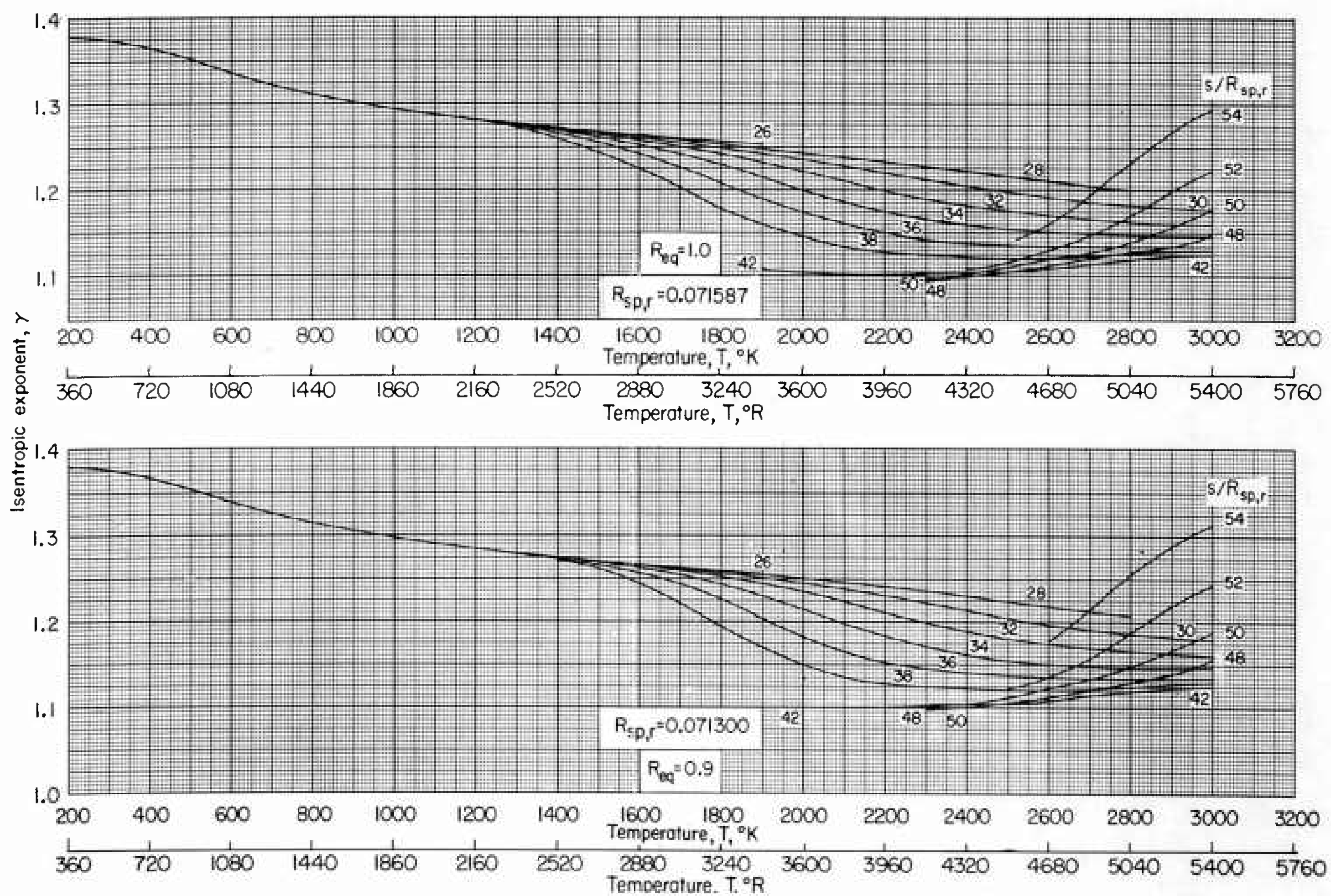


Figure 11.- Isentropic exponent for CH_4-air combustion products against temperature for constant entropy.

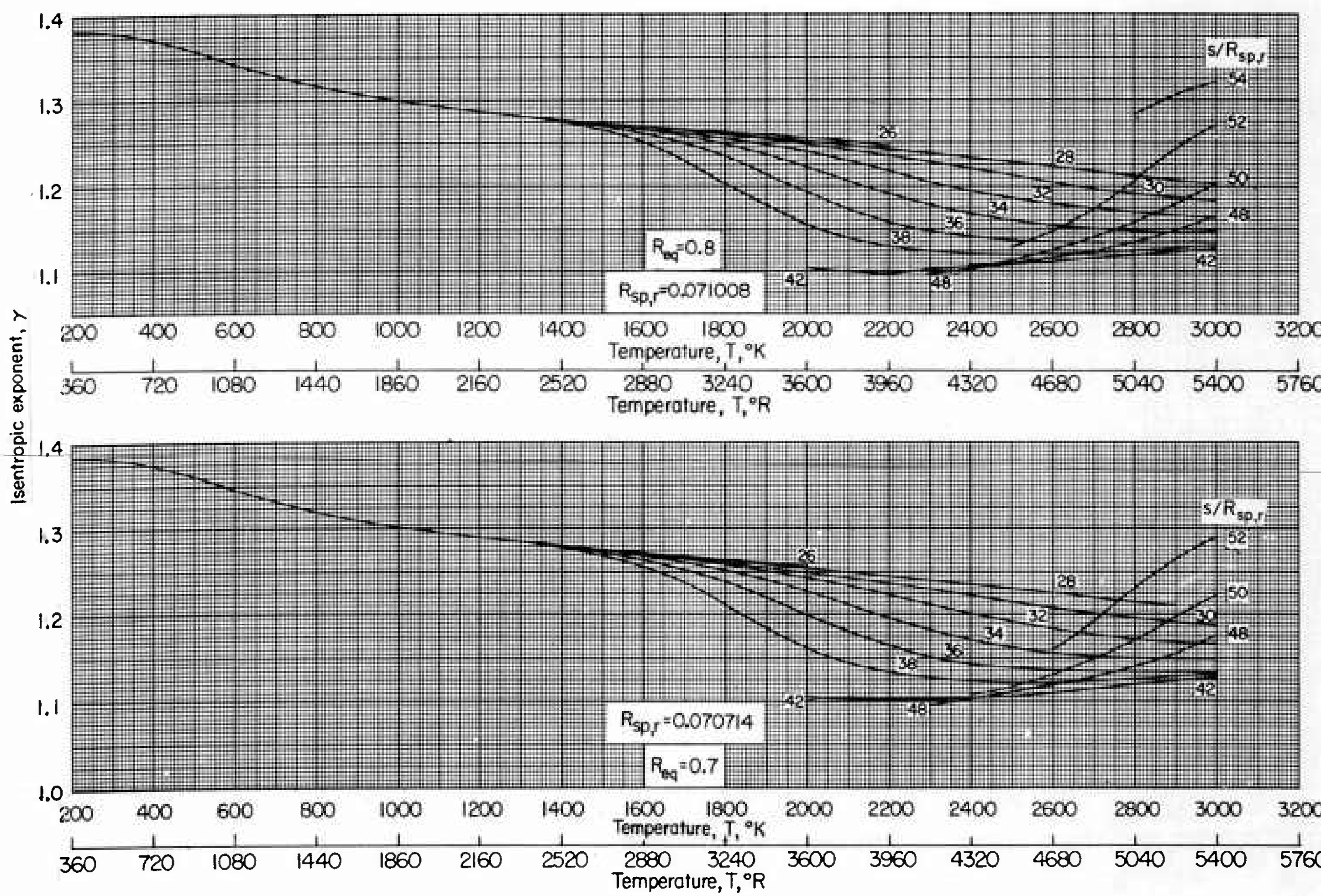


Figure 11.- Concluded.

L-1396

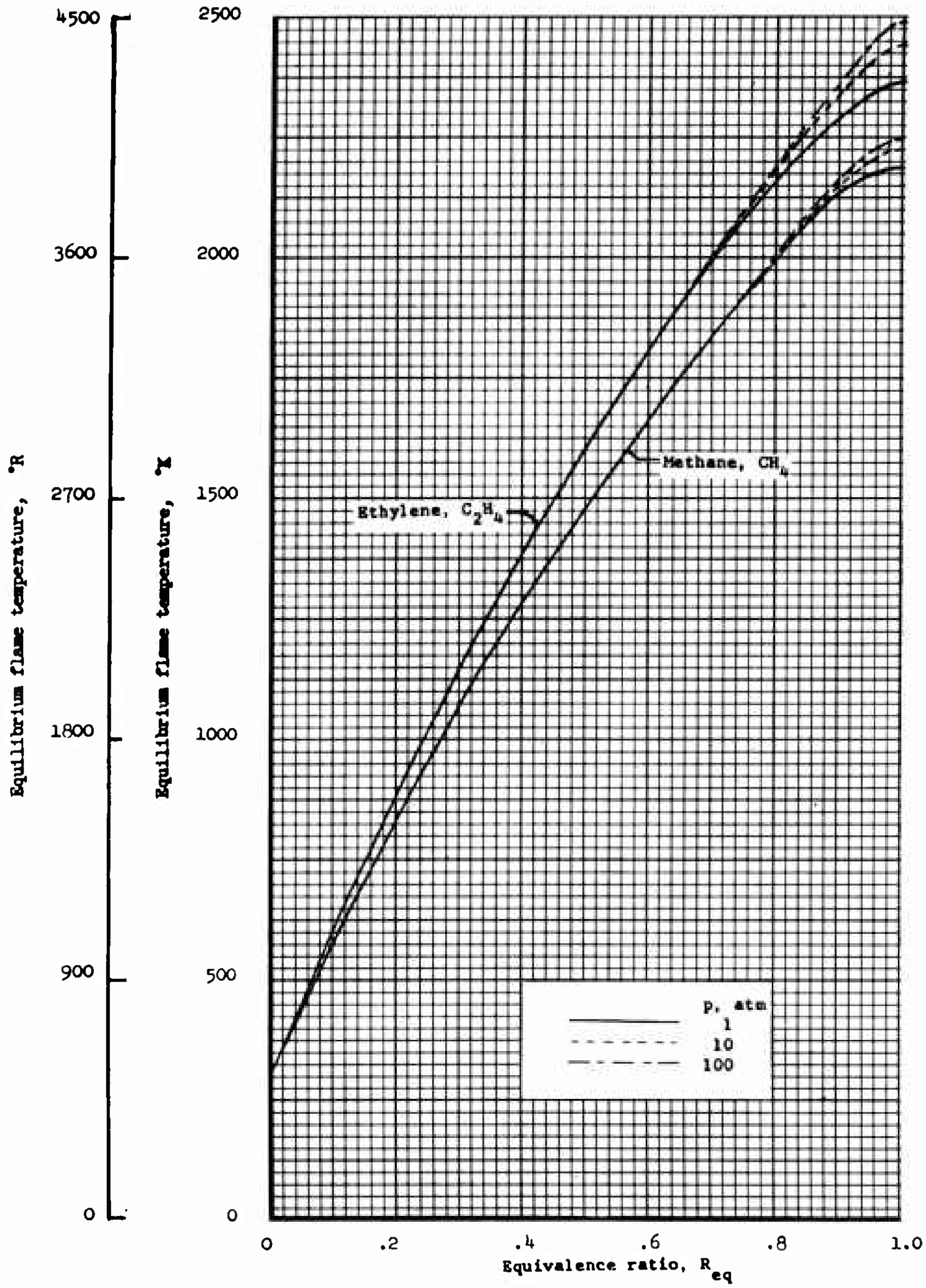
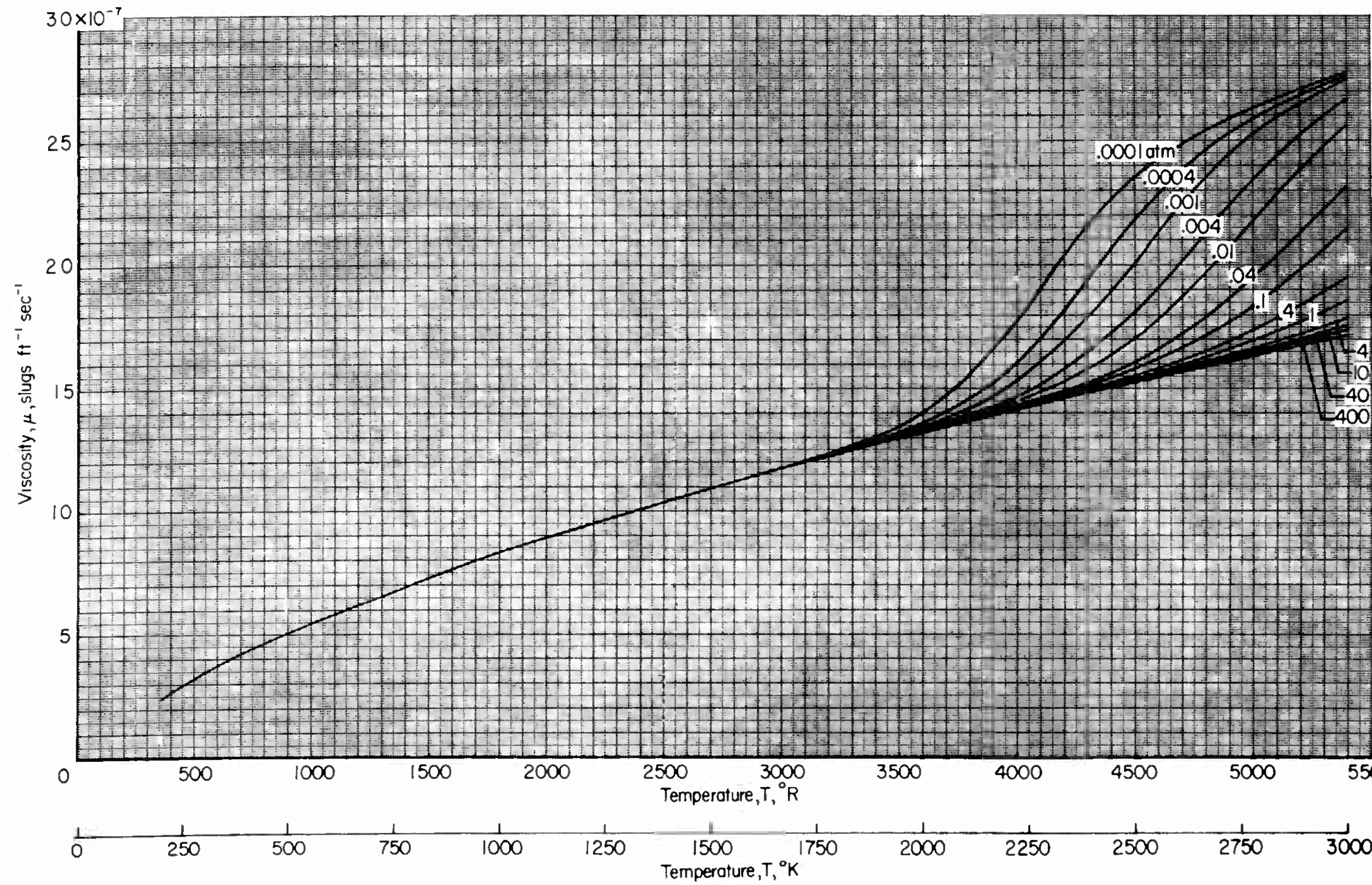
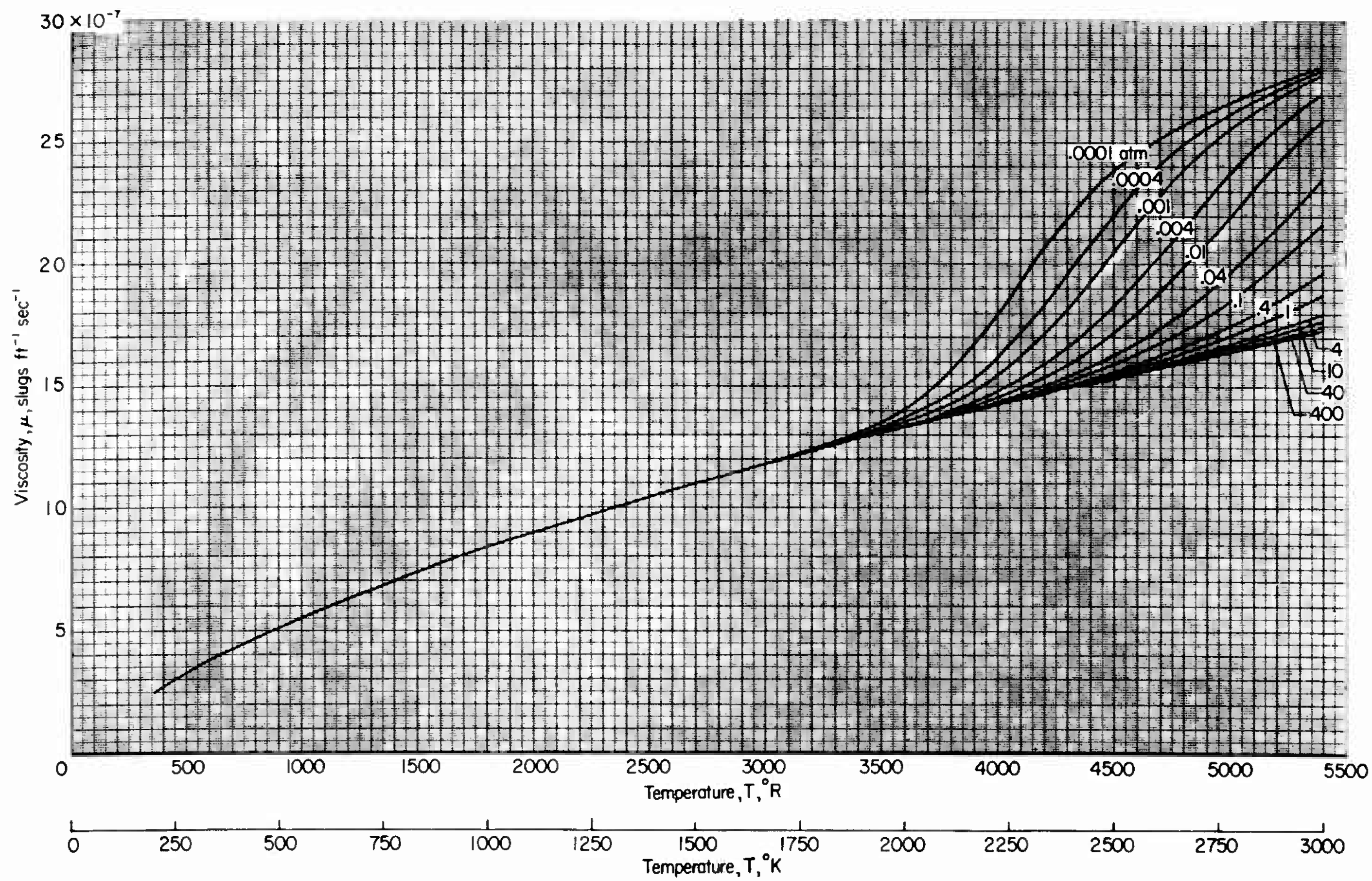


Figure 12.- The variation of equilibrium flame temperature with equivalence ratio for fuel lean mixtures of ethylene-air and methane-air at pressures of 1, 10, and 100 atmospheres.



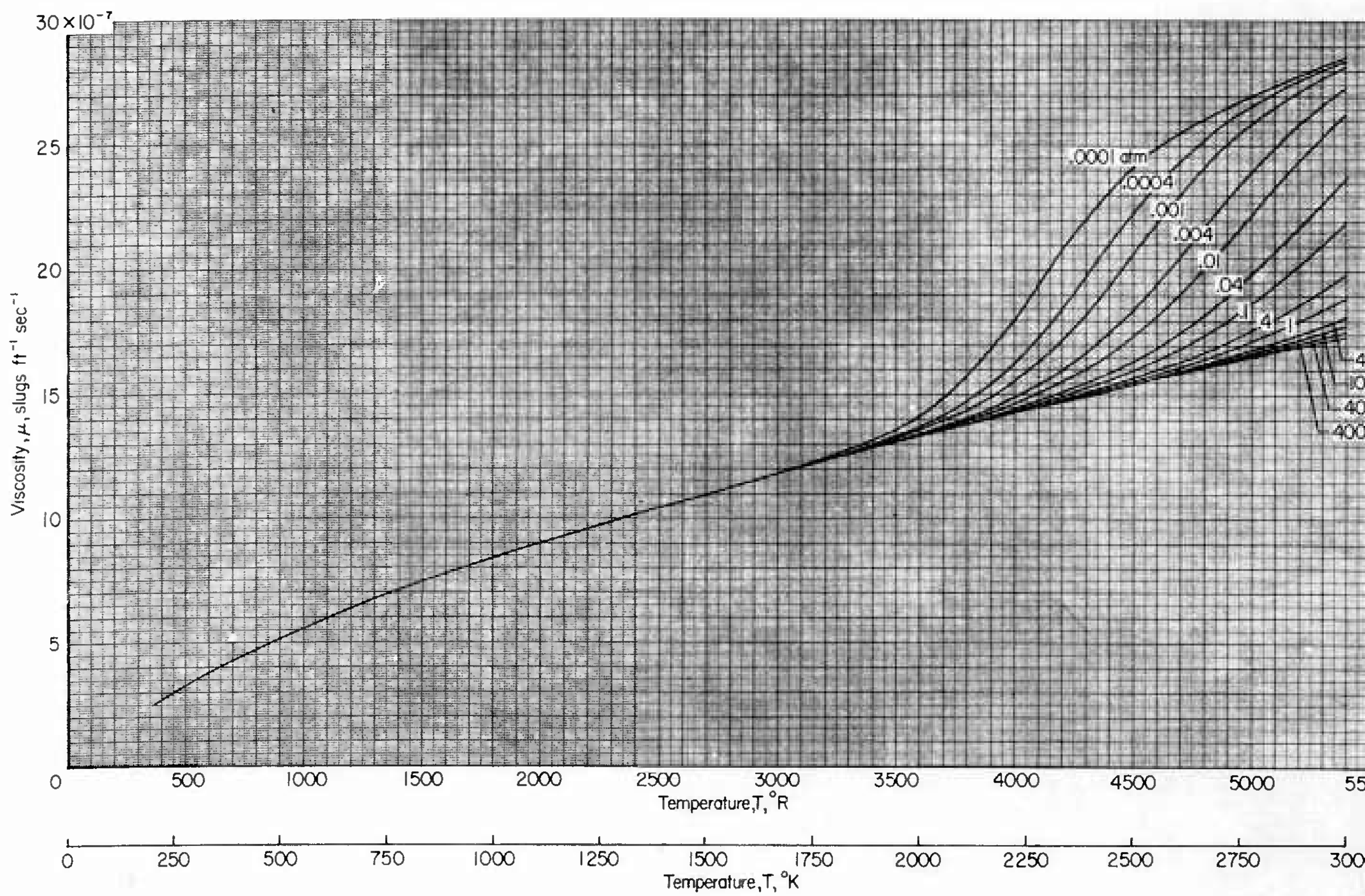
(a) Equivalence ratio, 1.0.

Figure 13.- Viscosity as a function of temperature for C_2H_4-air combustion products at various pressures and equivalence ratios.



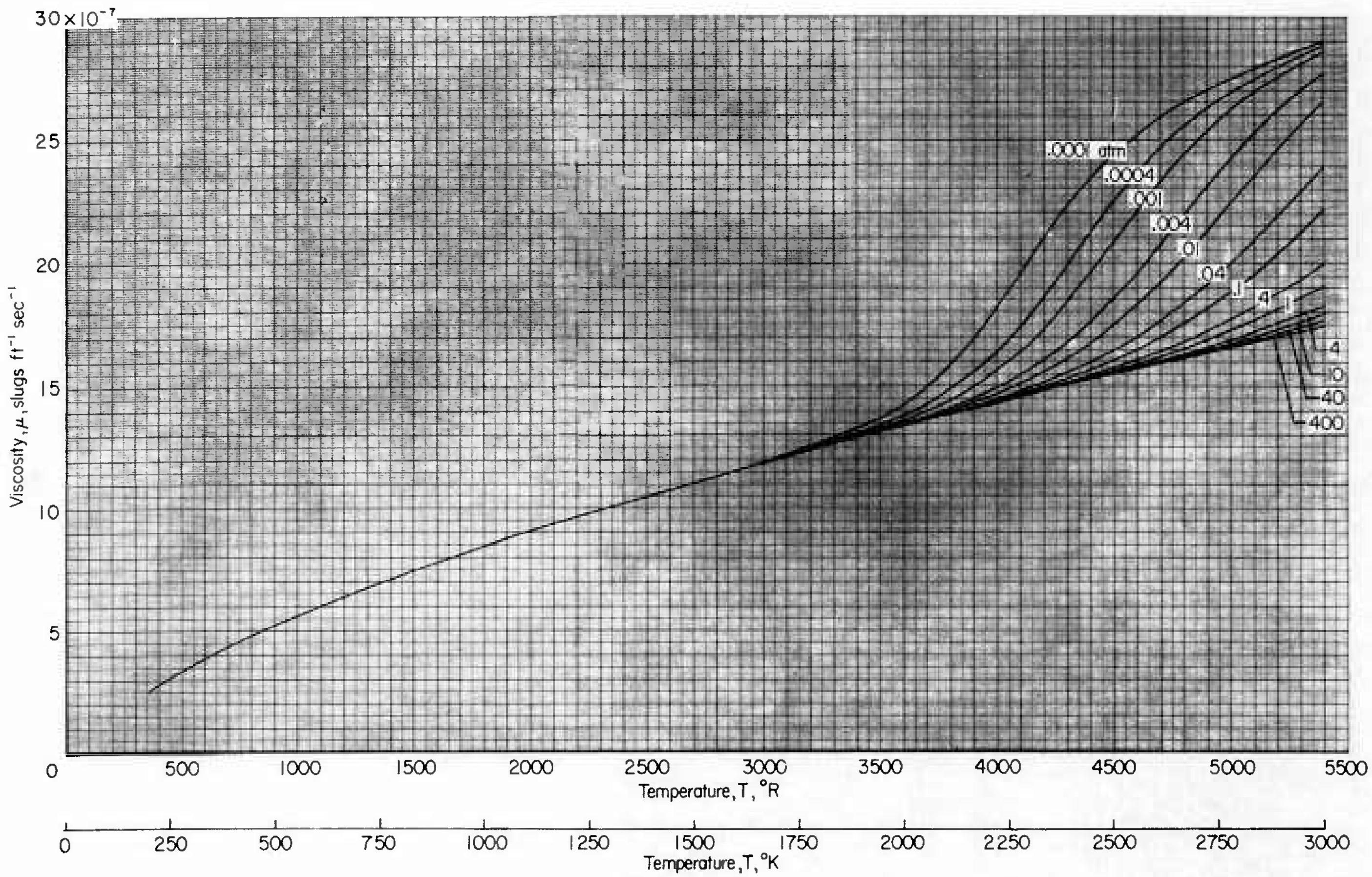
(b) Equivalence ratio, 0.9.

Figure 13.- Continued.



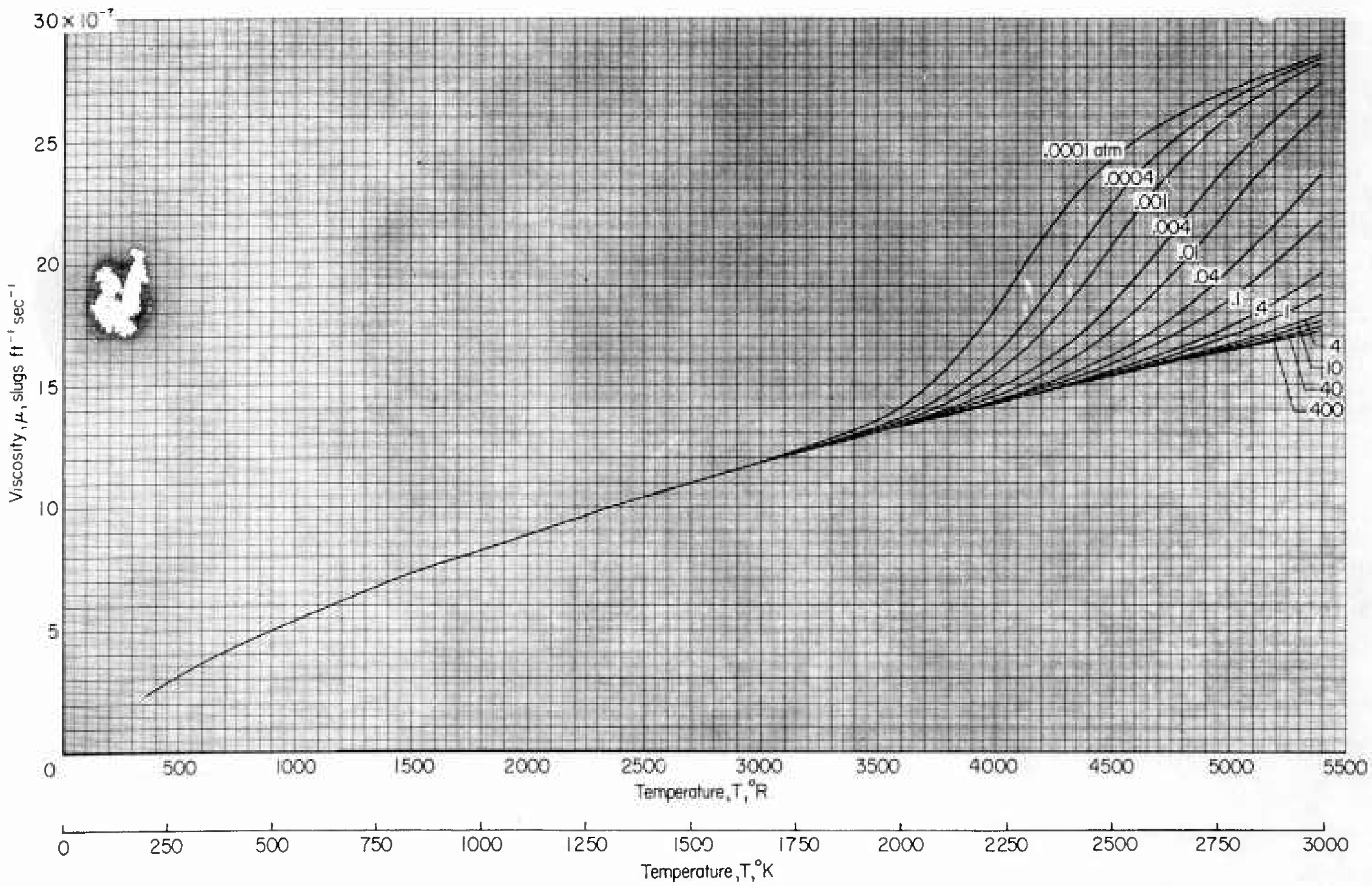
(c) Equivalence ratio, 0.8.

Figure 13.- Continued.



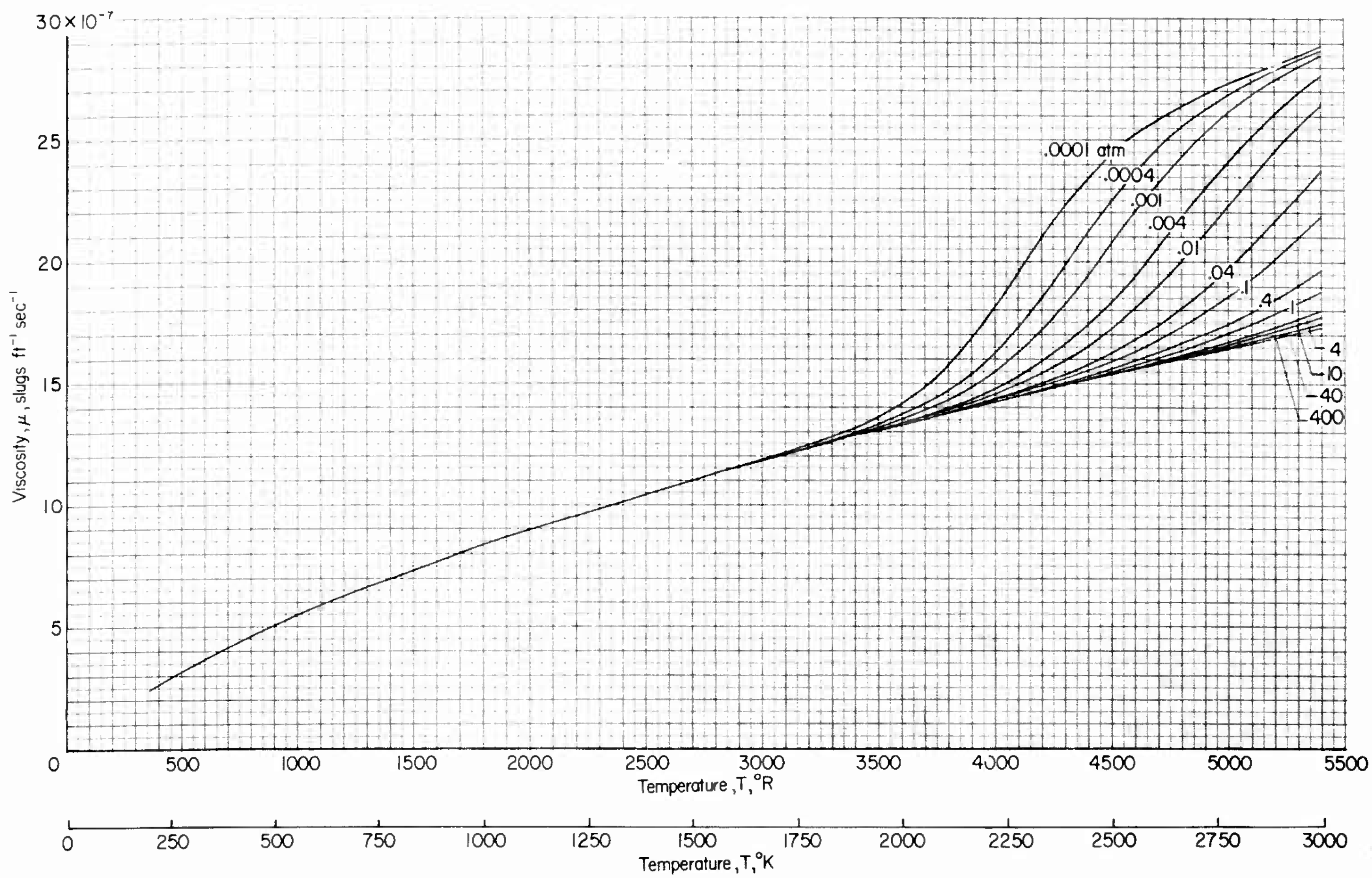
(d) Equivalence ratio, 0.7.

Figure 13.- Concluded.



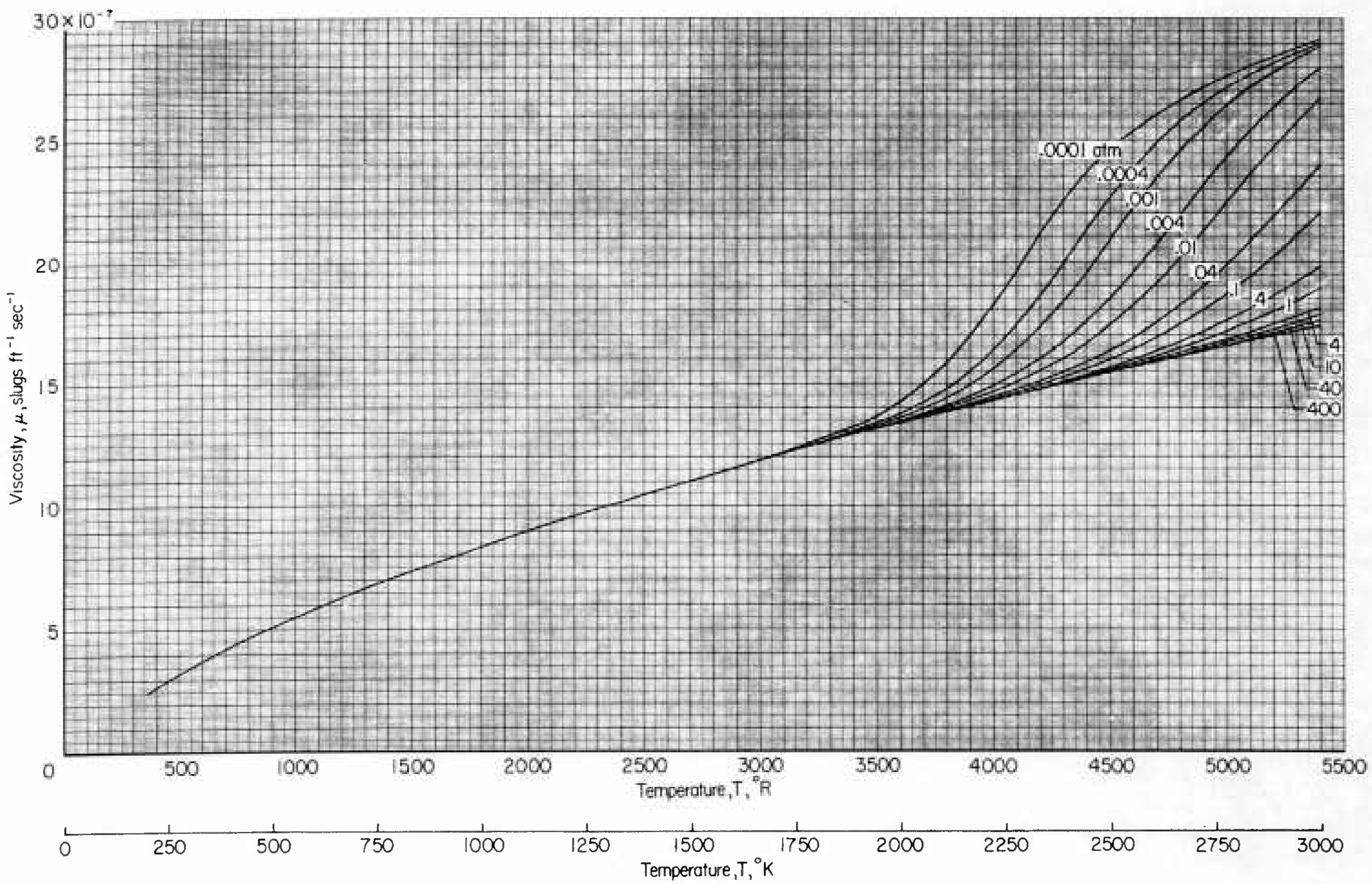
(a) Equivalence ratio, 1.0.

Figure 14.- Viscosity as a function of temperature for CH_4-air combustion products at various pressures and equivalence ratios.



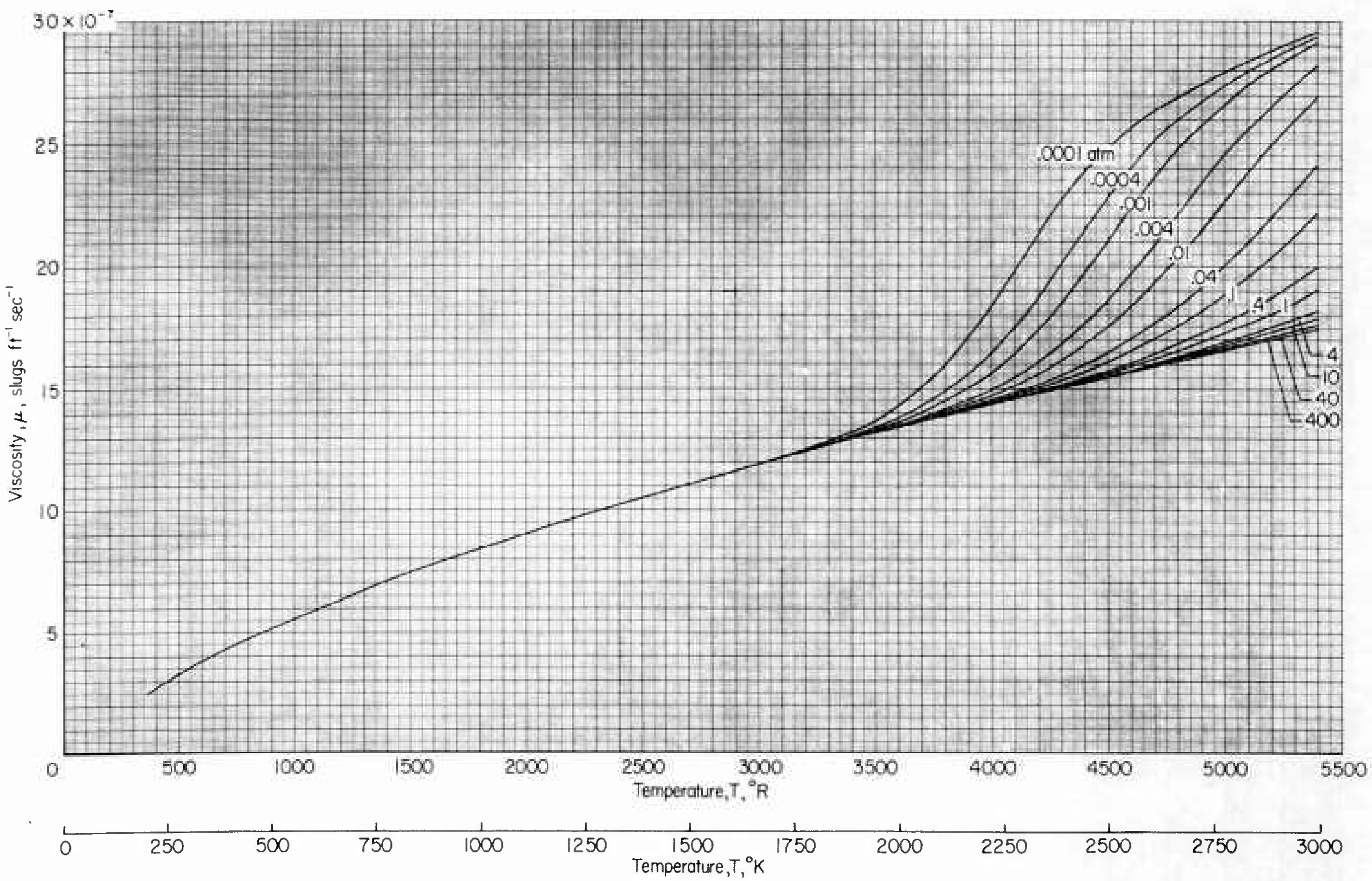
(b) Equivalence ratio, 0.9.

Figure 14.- Continued.



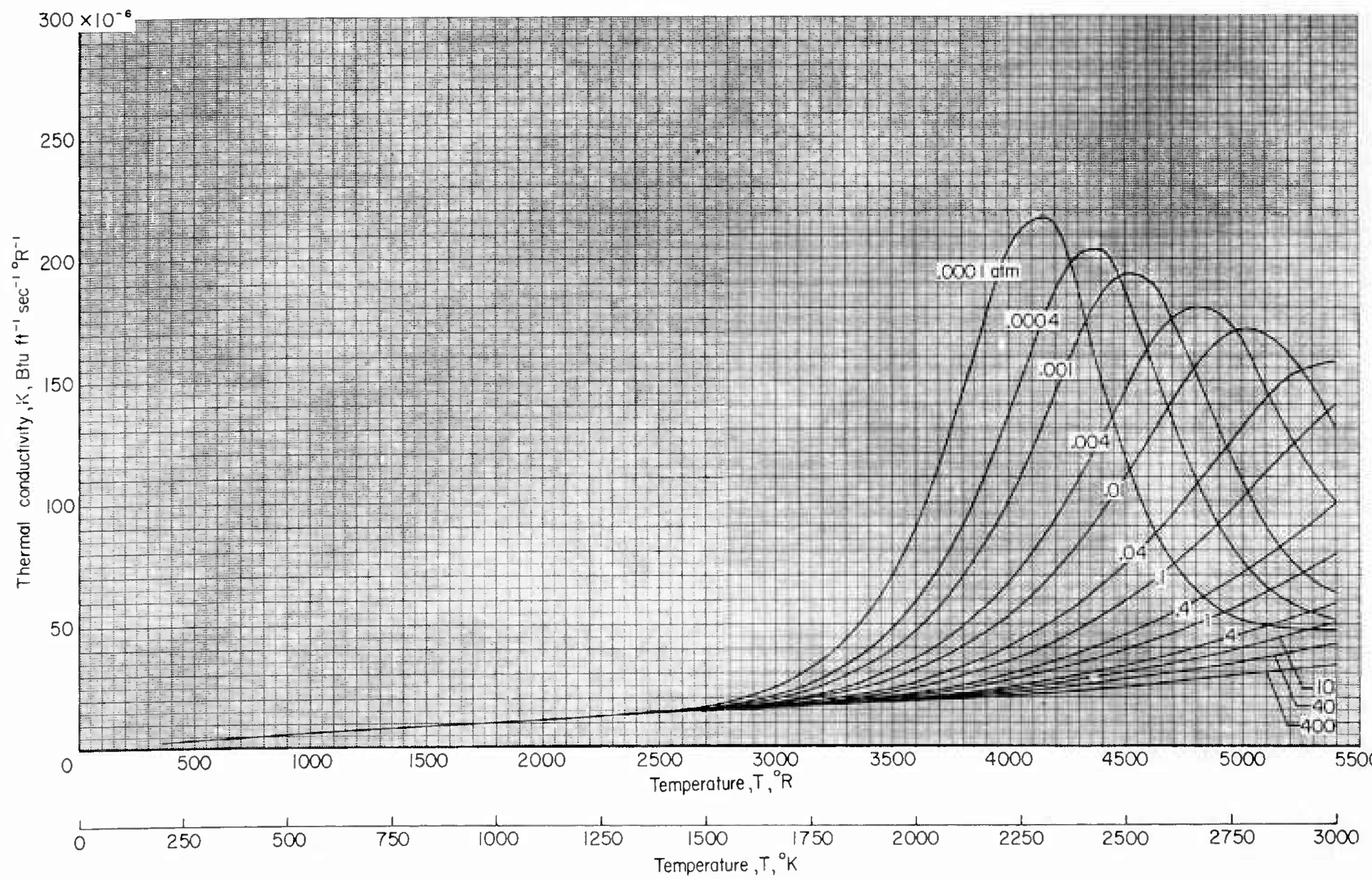
(c) Equivalence ratio, 0.8.

Figure 14.- Continued.



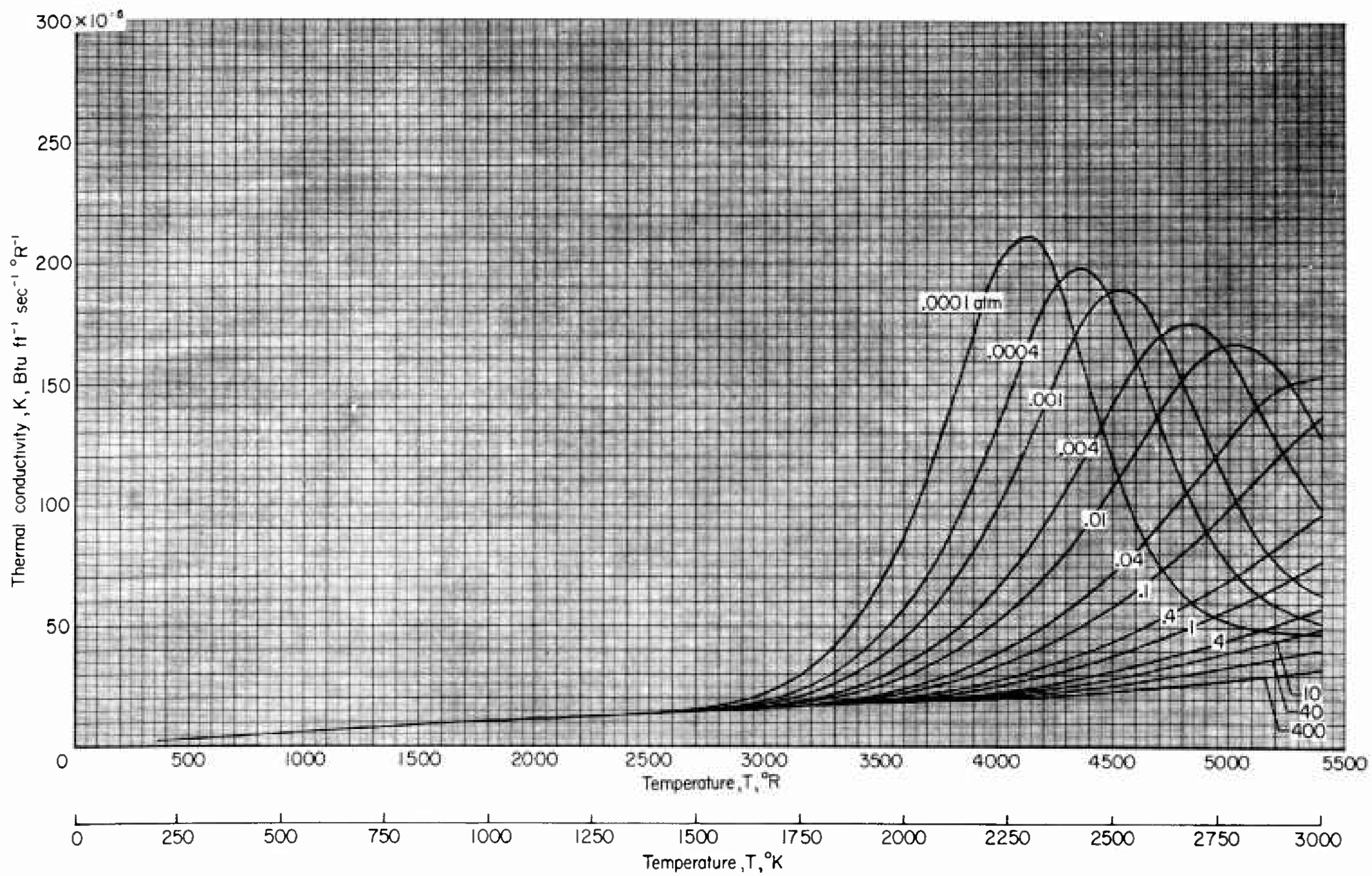
(d) Equivalence ratio, 0.7.

Figure 14.- Concluded.



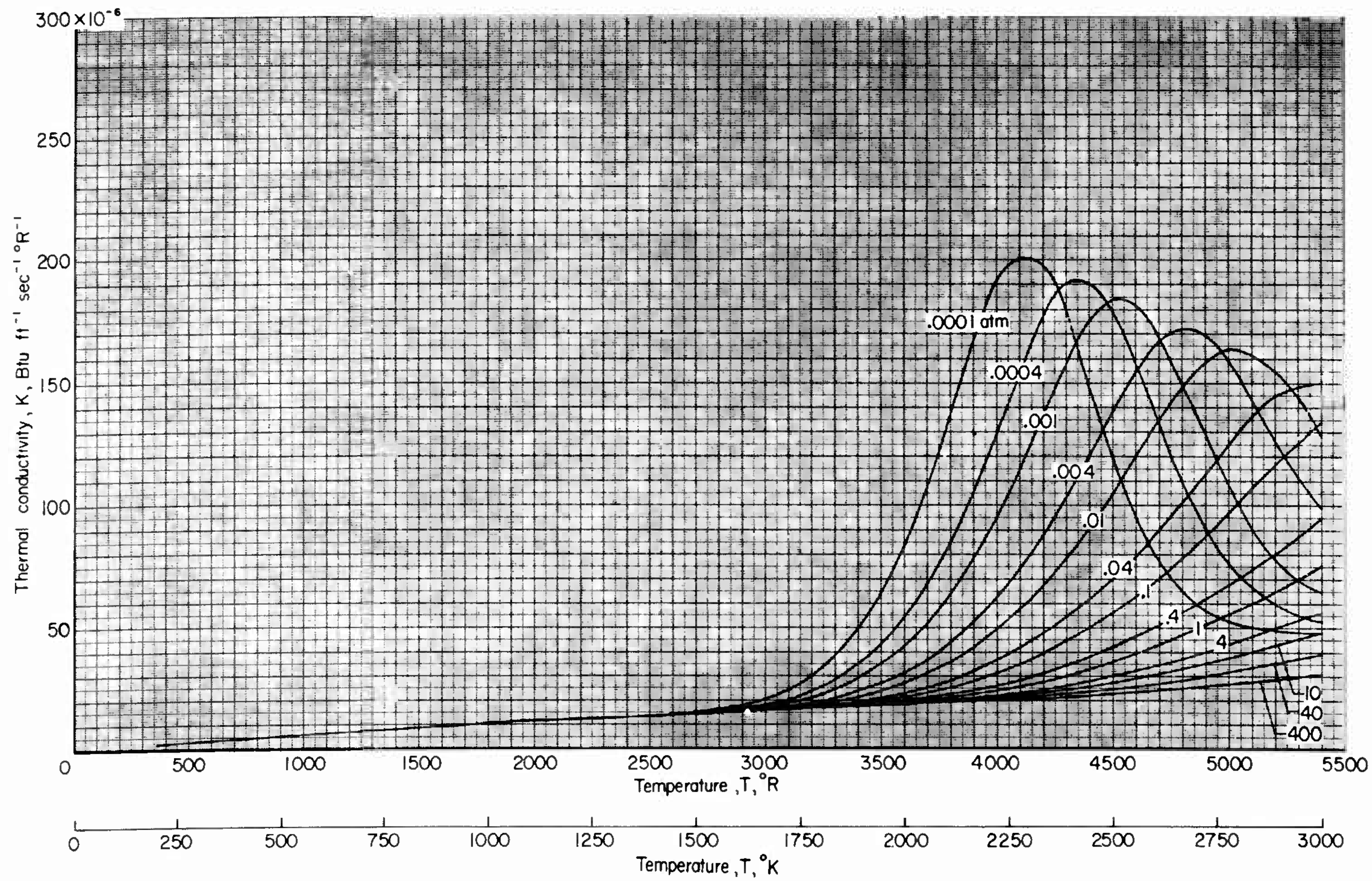
(a) Equivalence ratio, 1.0.

Figure 15.- Thermal conductivity as a function of temperature for C_2H_4-air combustion products at various pressures and equivalence ratios.



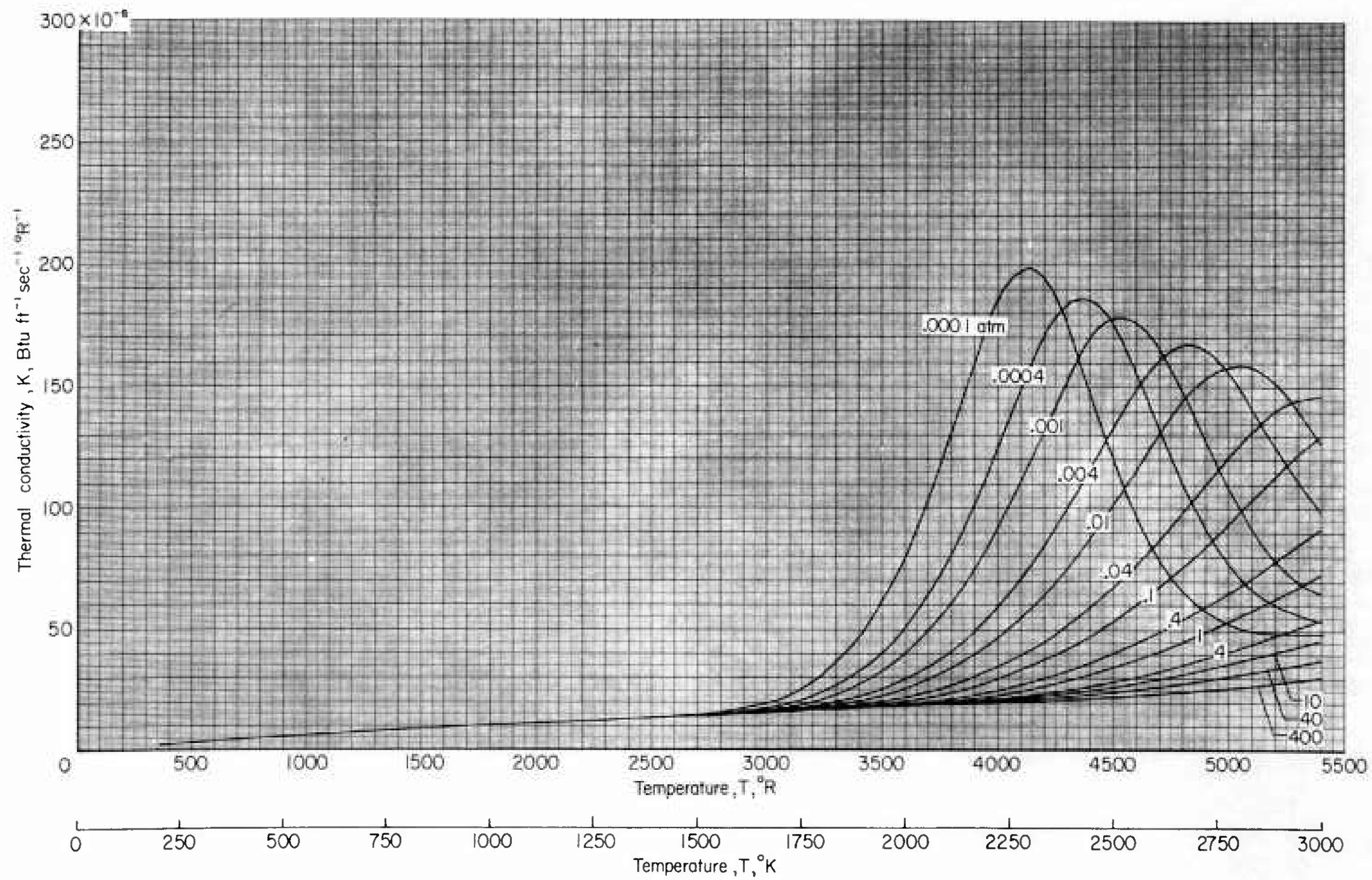
(b) Equivalence ratio, 0.9.

Figure 15.- Continued.



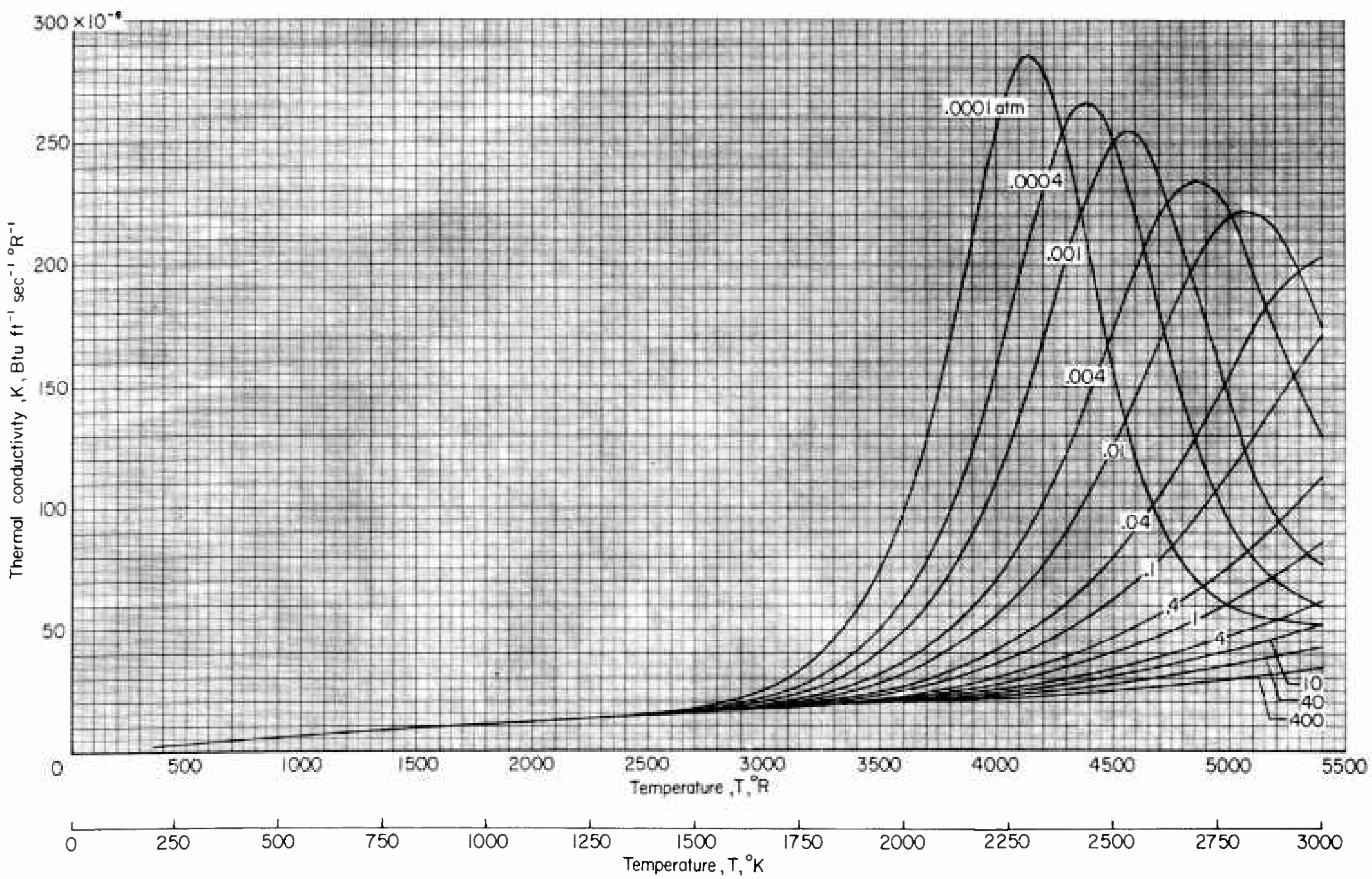
(c) Equivalence ratio, 0.8.

Figure 15.- Continued.



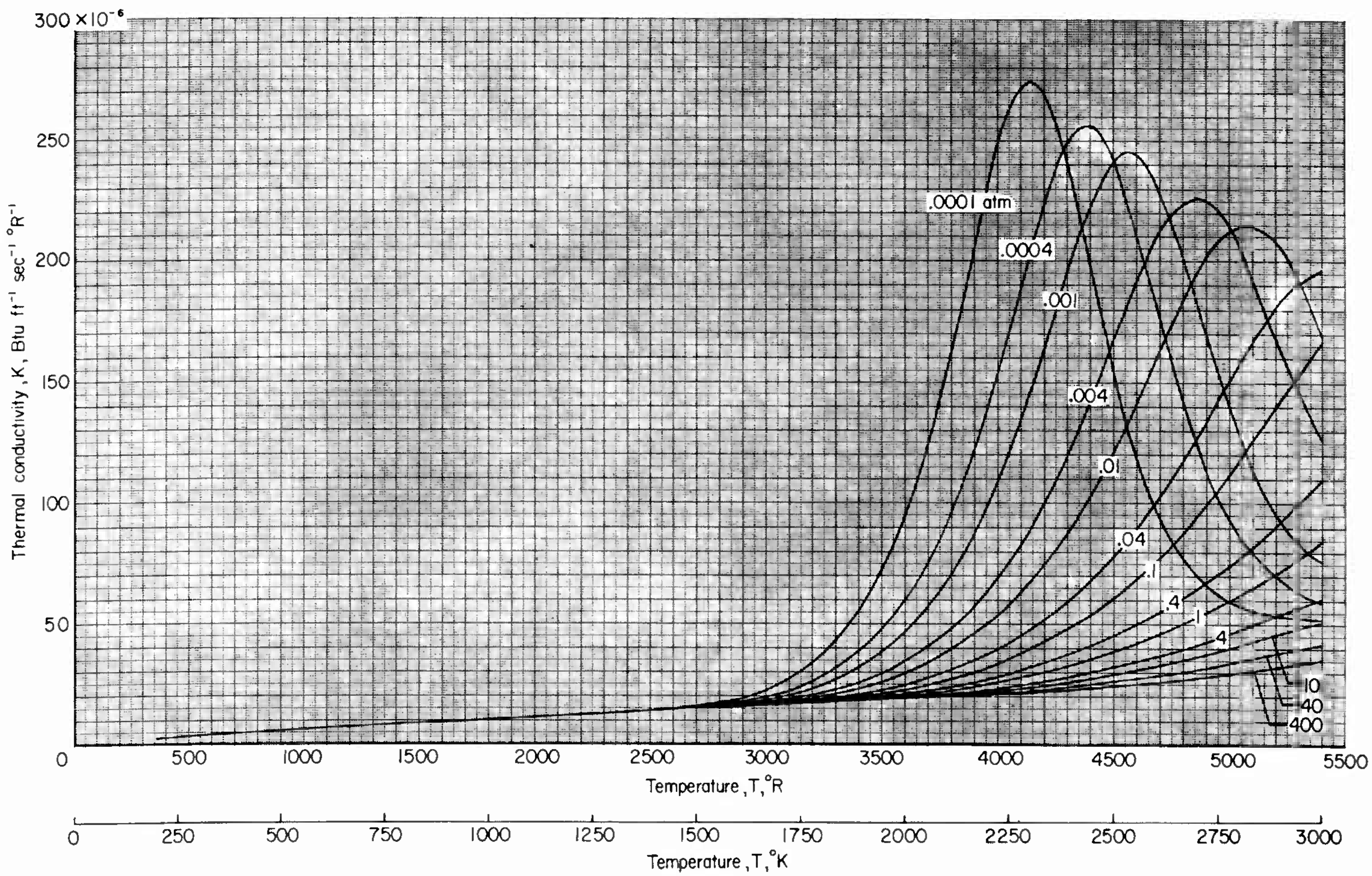
(d) Equivalence ratio, 0.7.

Figure 15.- Concluded.



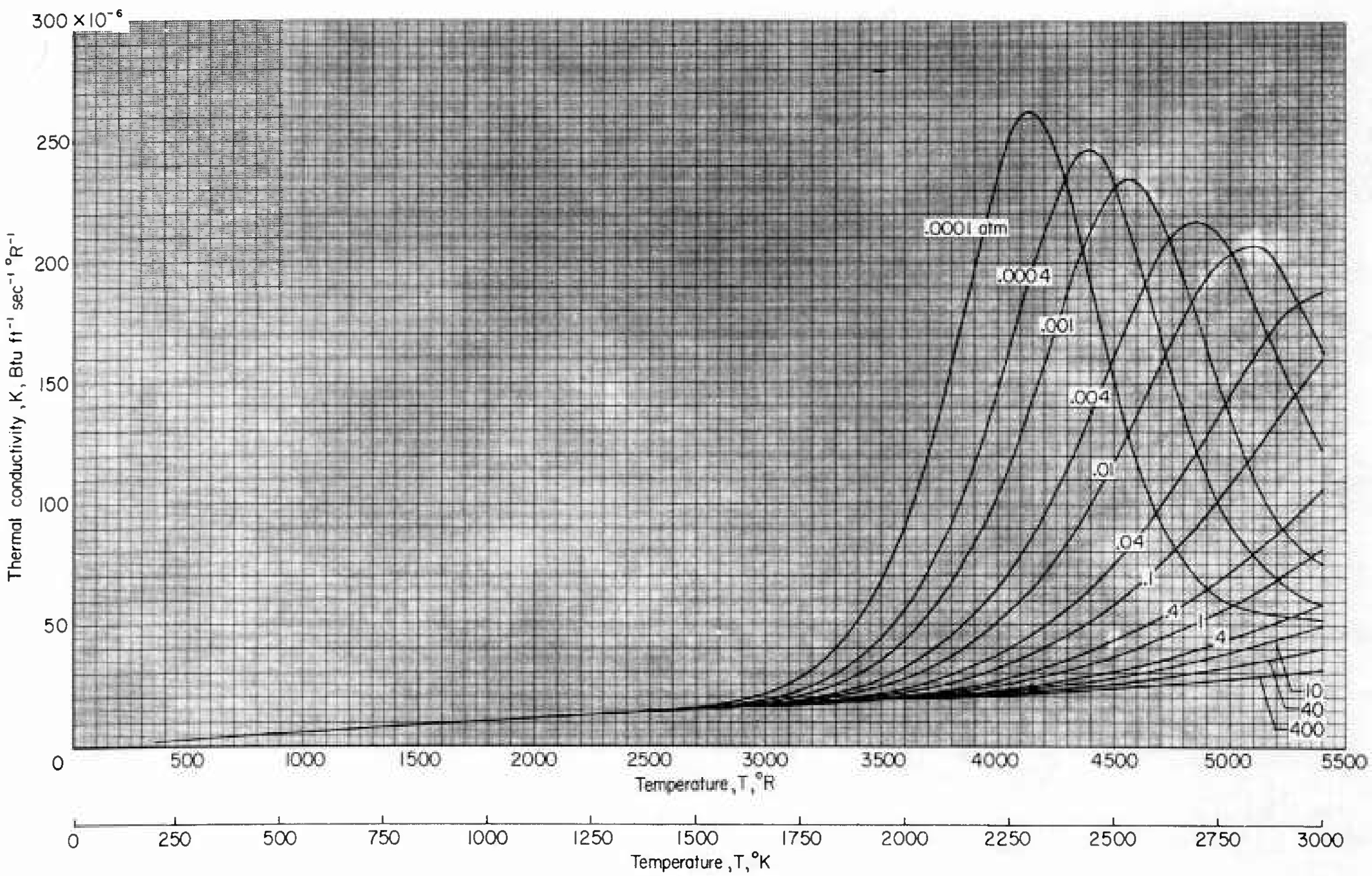
(a) Equivalence ratio, 1.0.

Figure 16.- Thermal conductivity as a function of temperature for CH_4-air combustion products at various pressures and equivalence ratios.



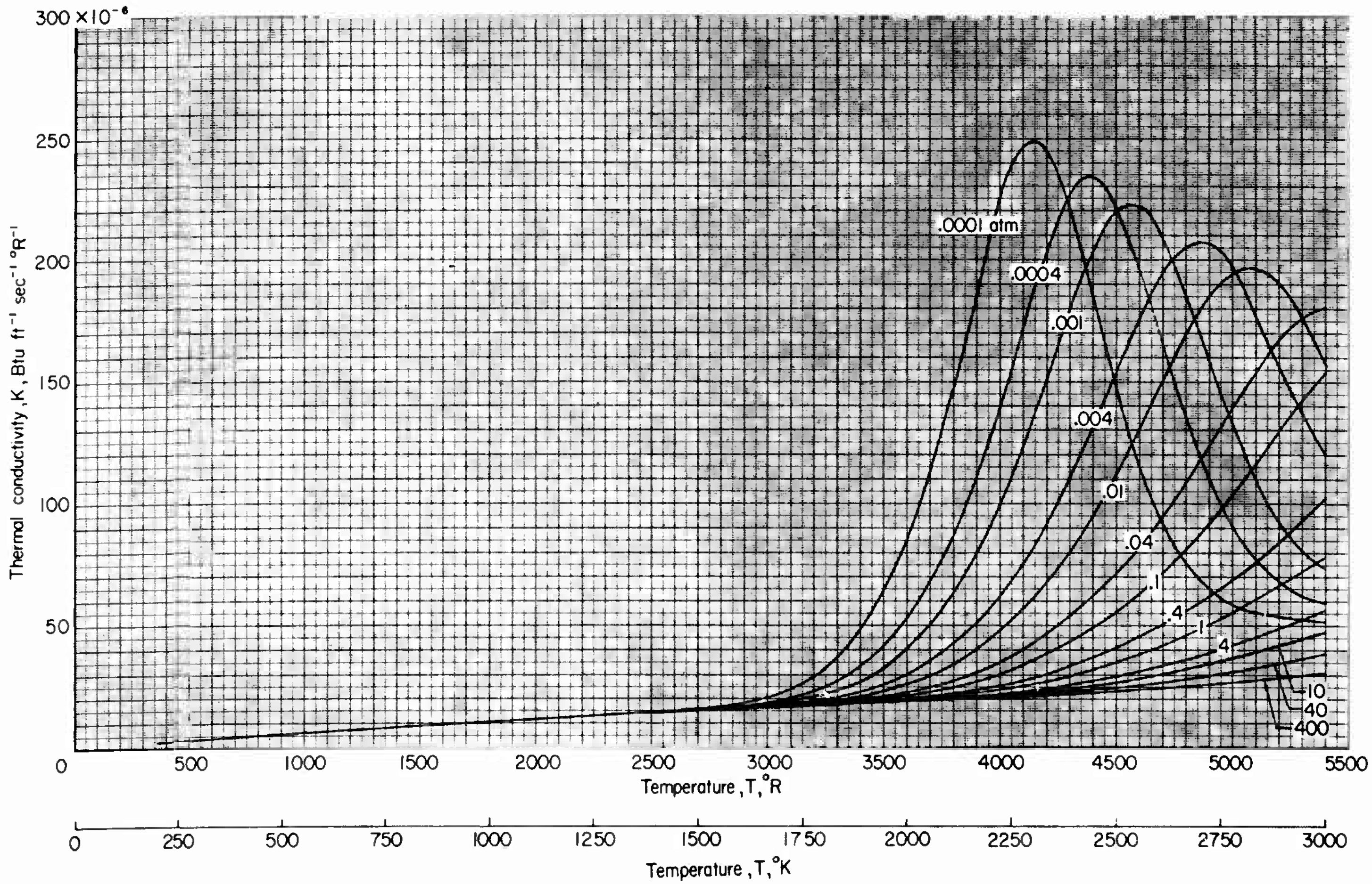
(b) Equivalence ratio, 0.9.

Figure 16.- Continued.



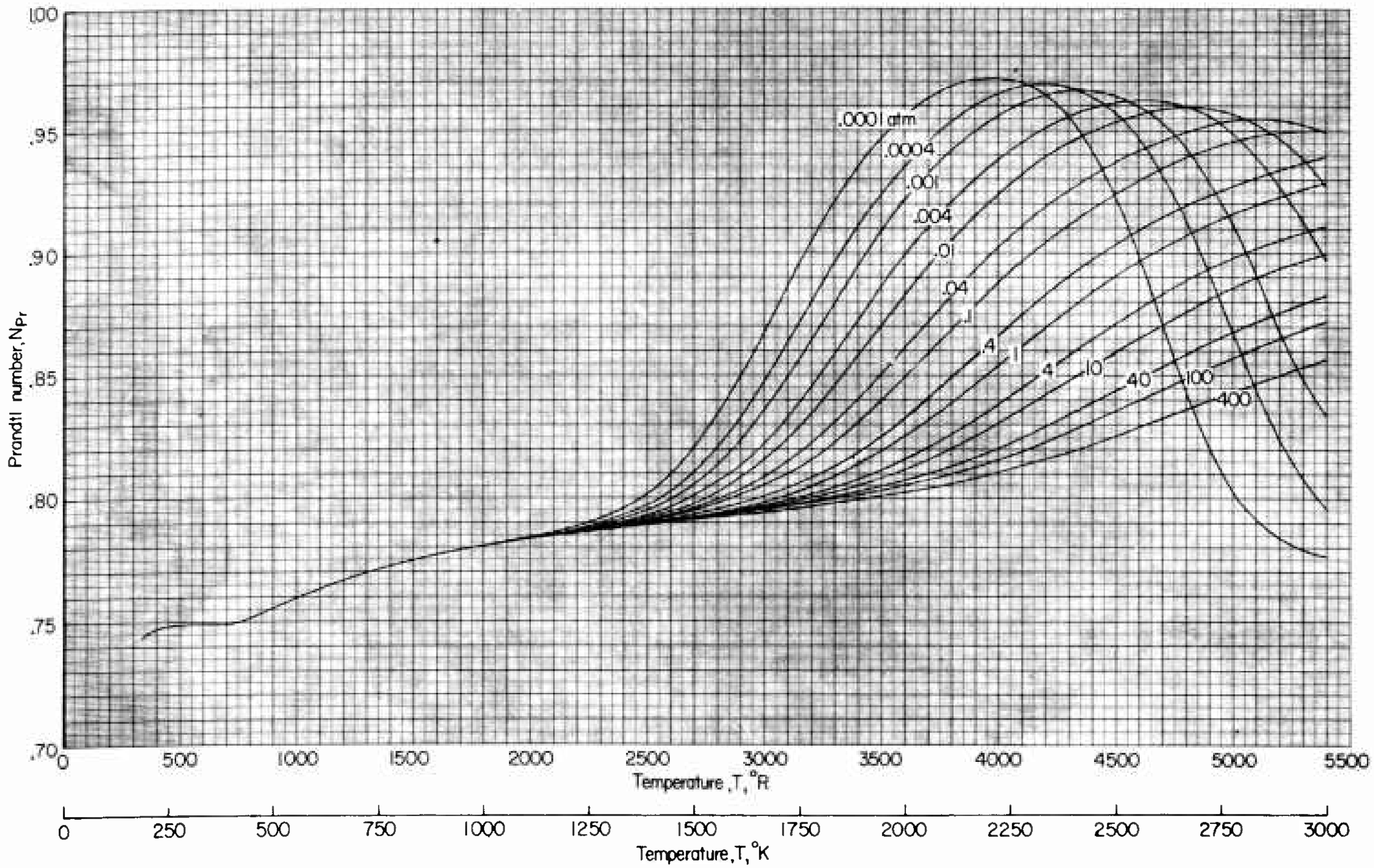
(c) Equivalence ratio, 0.8.

Figure 16.- Continued.



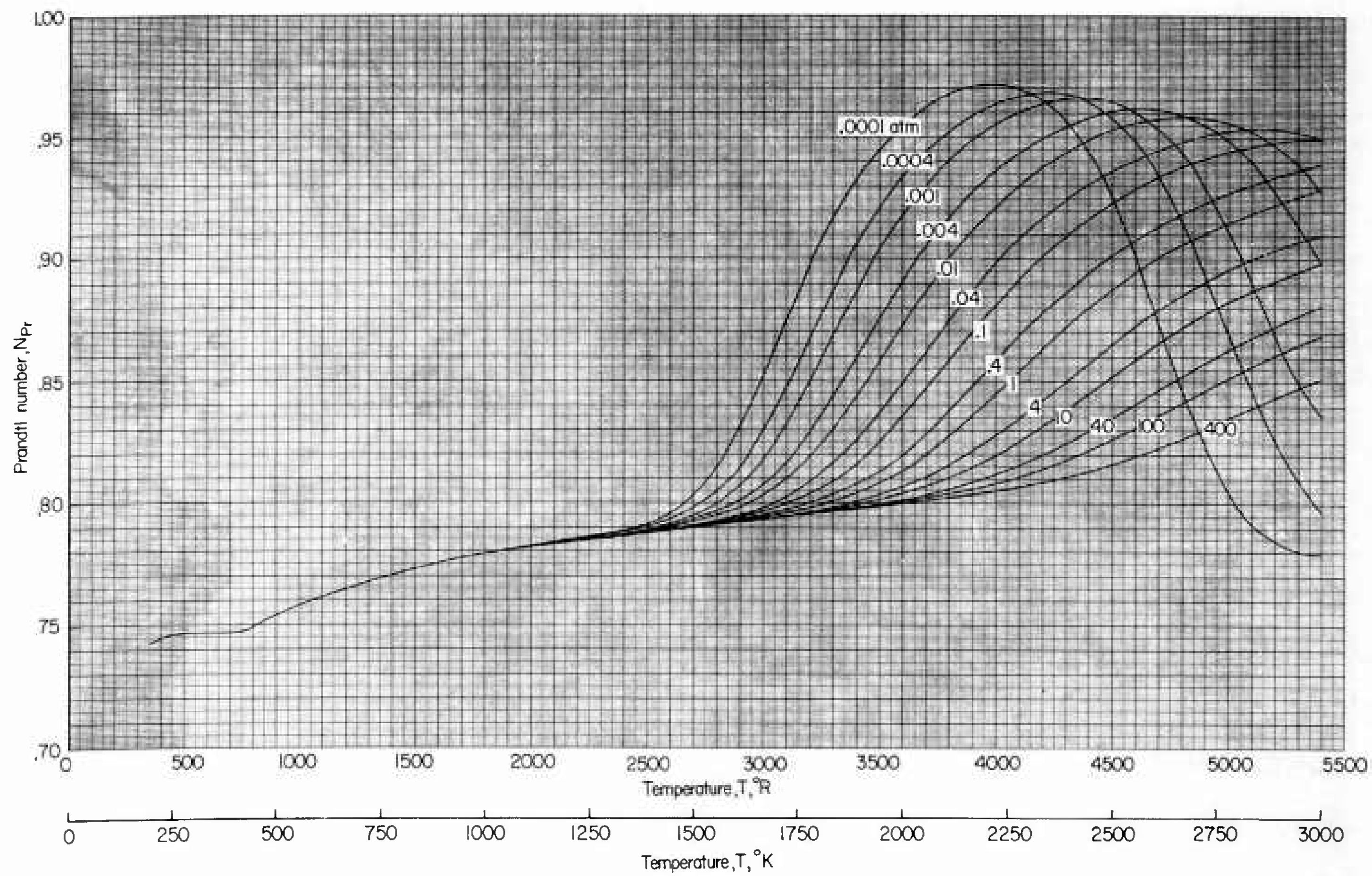
(d) Equivalence ratio, 0.7.

Figure 16.- Concluded.



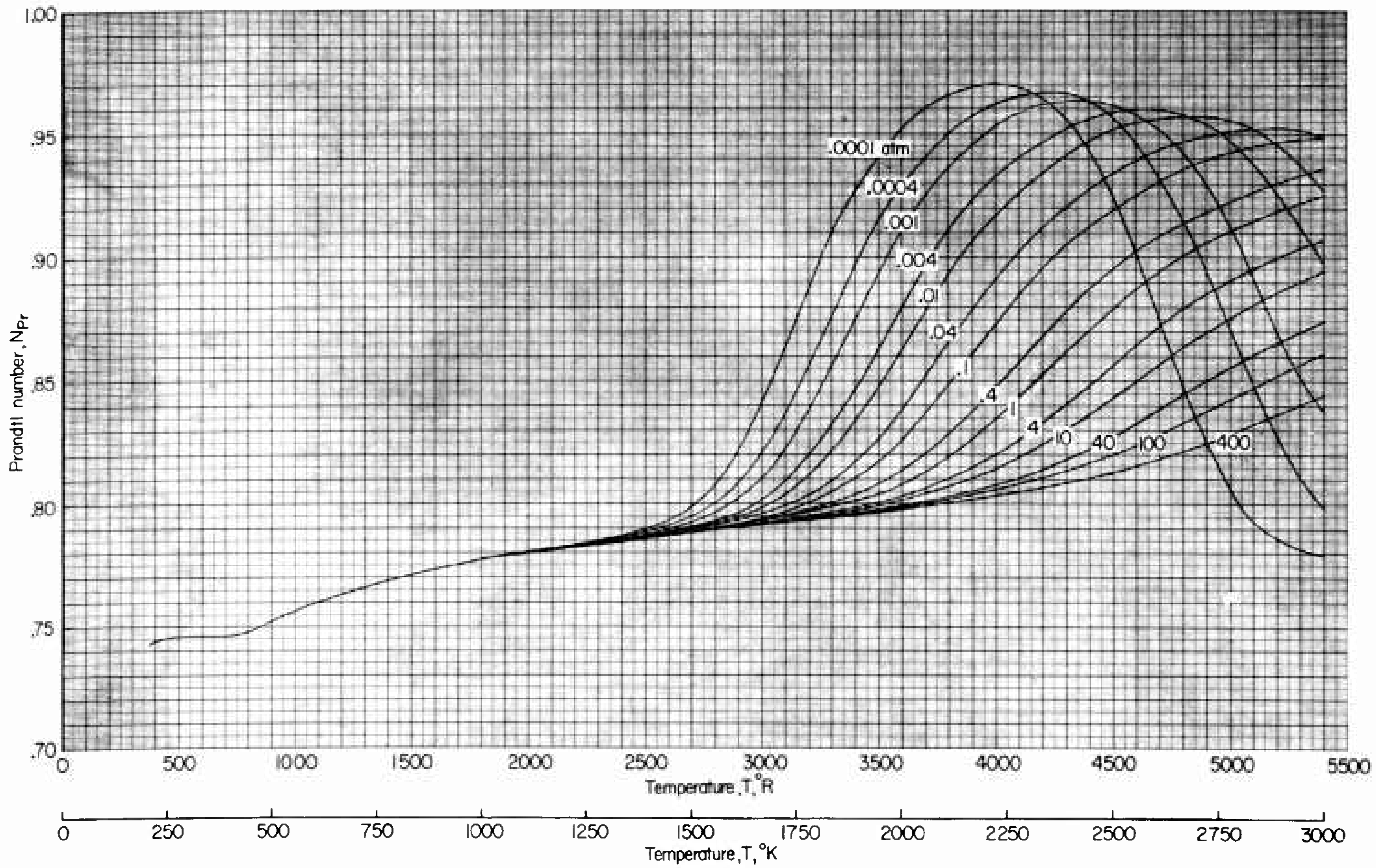
(a) Equivalence ratio, 1.0.

Figure 17.- Prandtl number as a function of temperature for C_2H_4-air combustion products at various pressures and equivalence ratios.



(b) Equivalence ratio, 0.9.

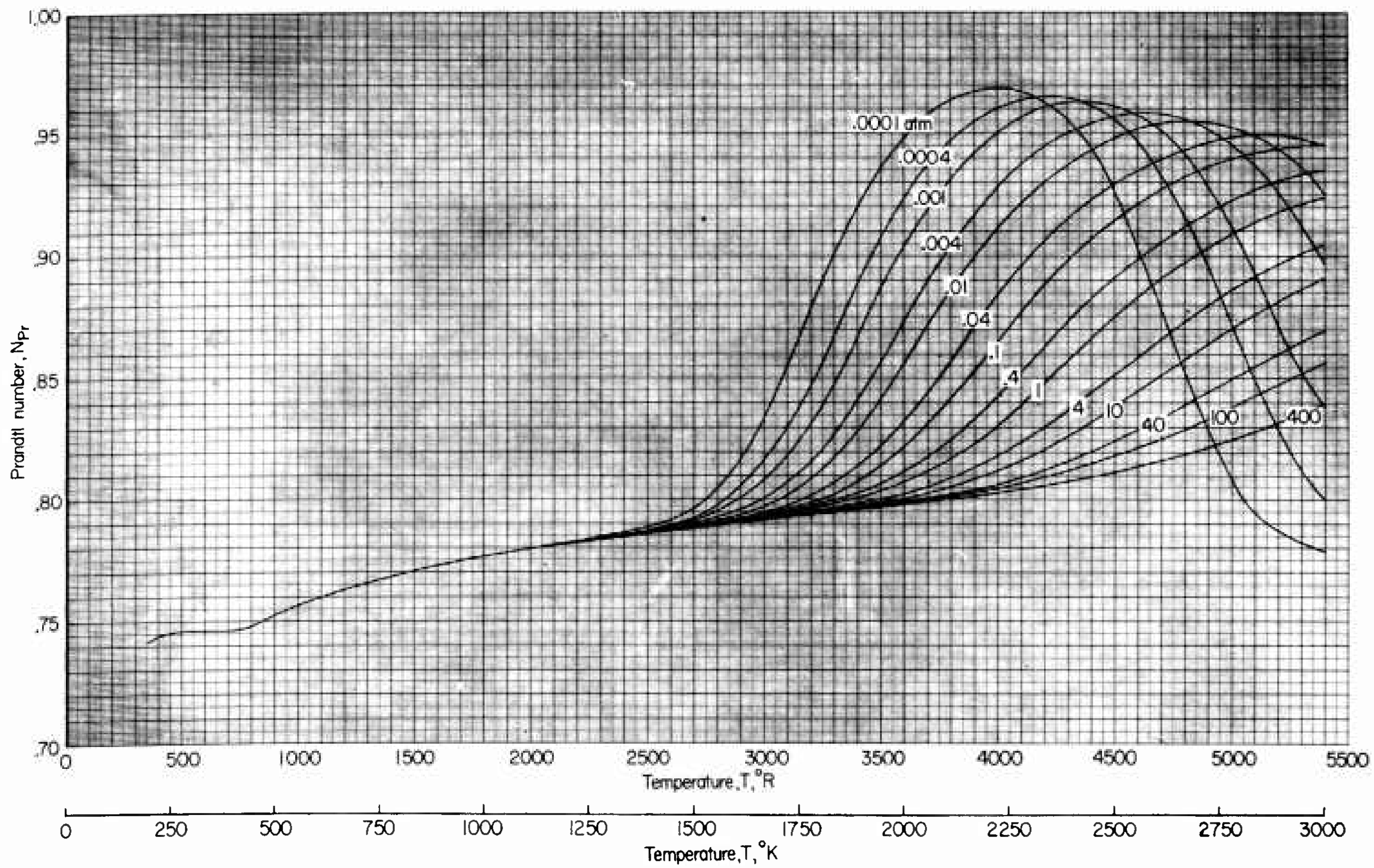
Figure 17.- Continued.



(c) Equivalence ratio, 0.8.

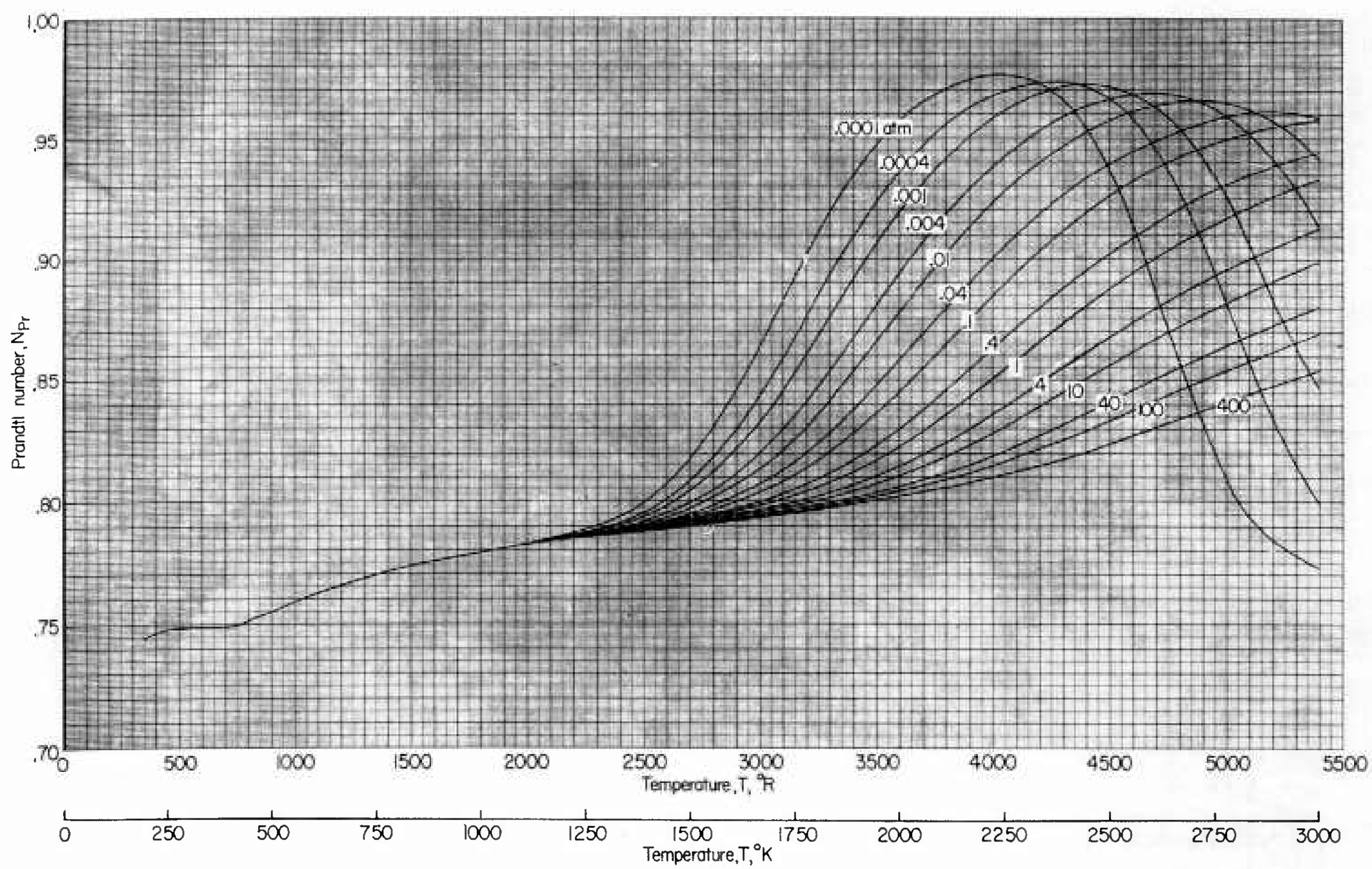
Figure 17.- Continued.

L-1396



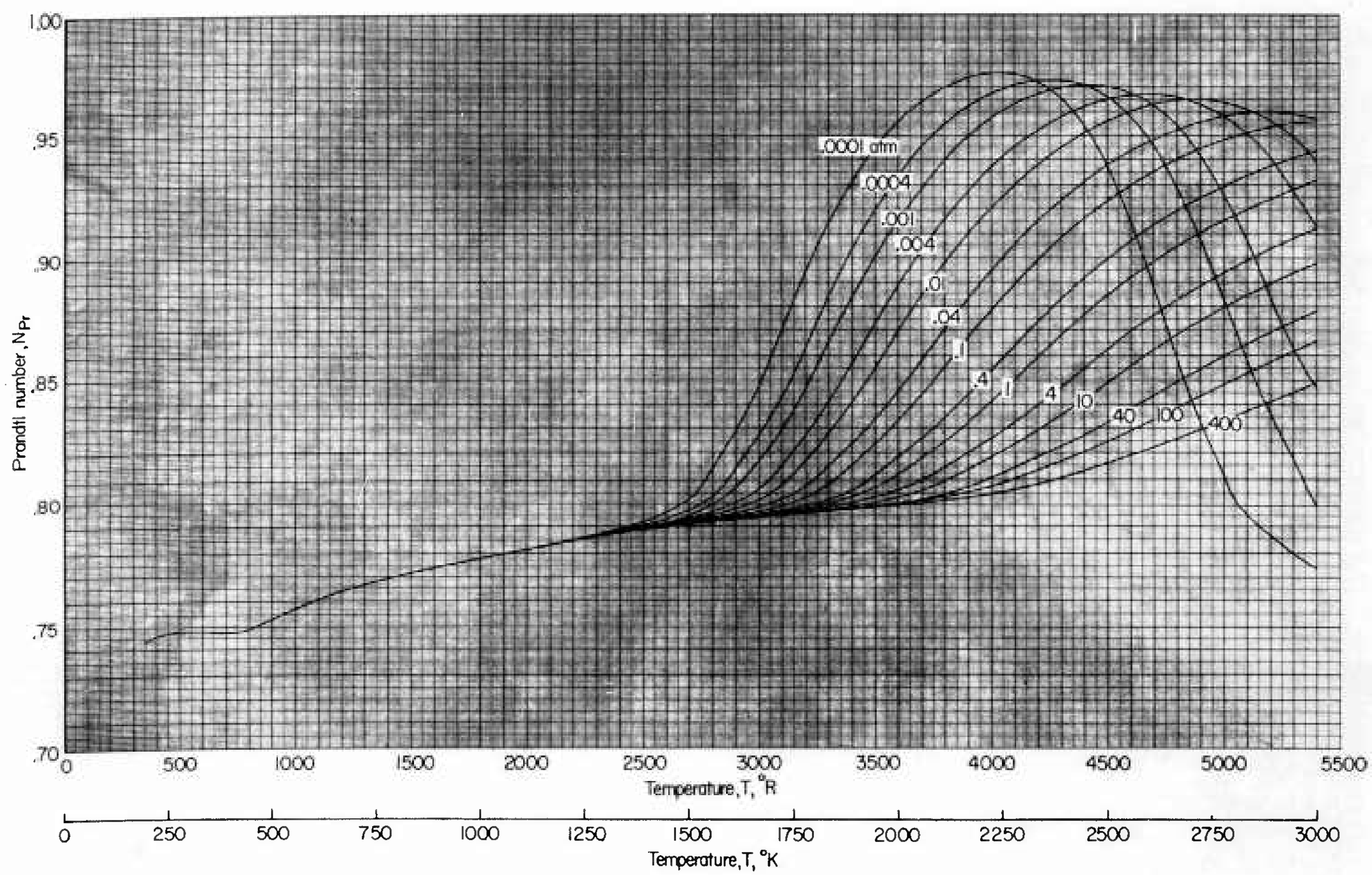
(d) Equivalence ratio, 0.7.

Figure 17.- Concluded.



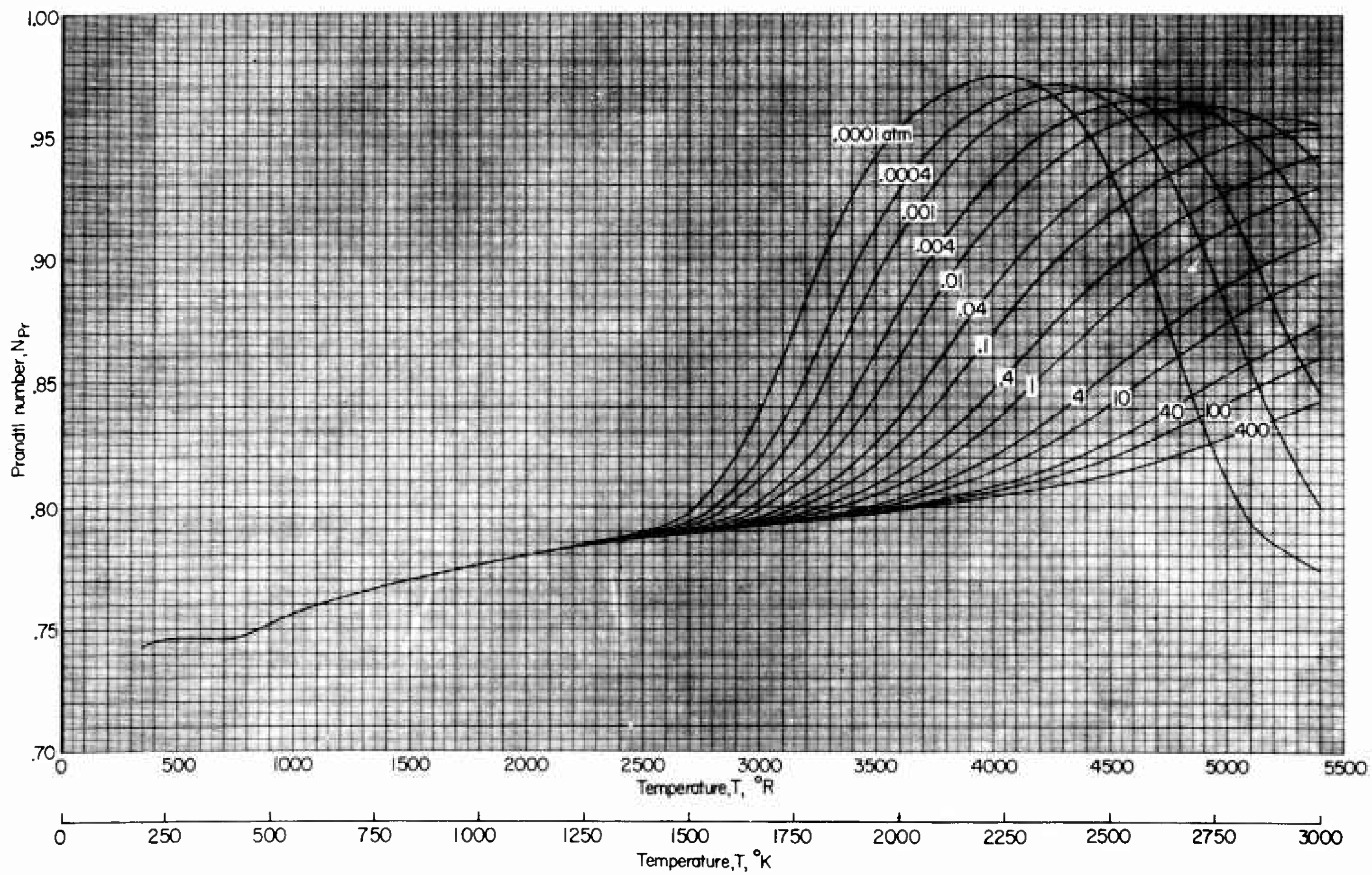
(a) Equivalence ratio, 1.0.

Figure 18.- Prandtl number as a function of temperature for CH_4-air combustion products at various pressures and equivalence ratios.



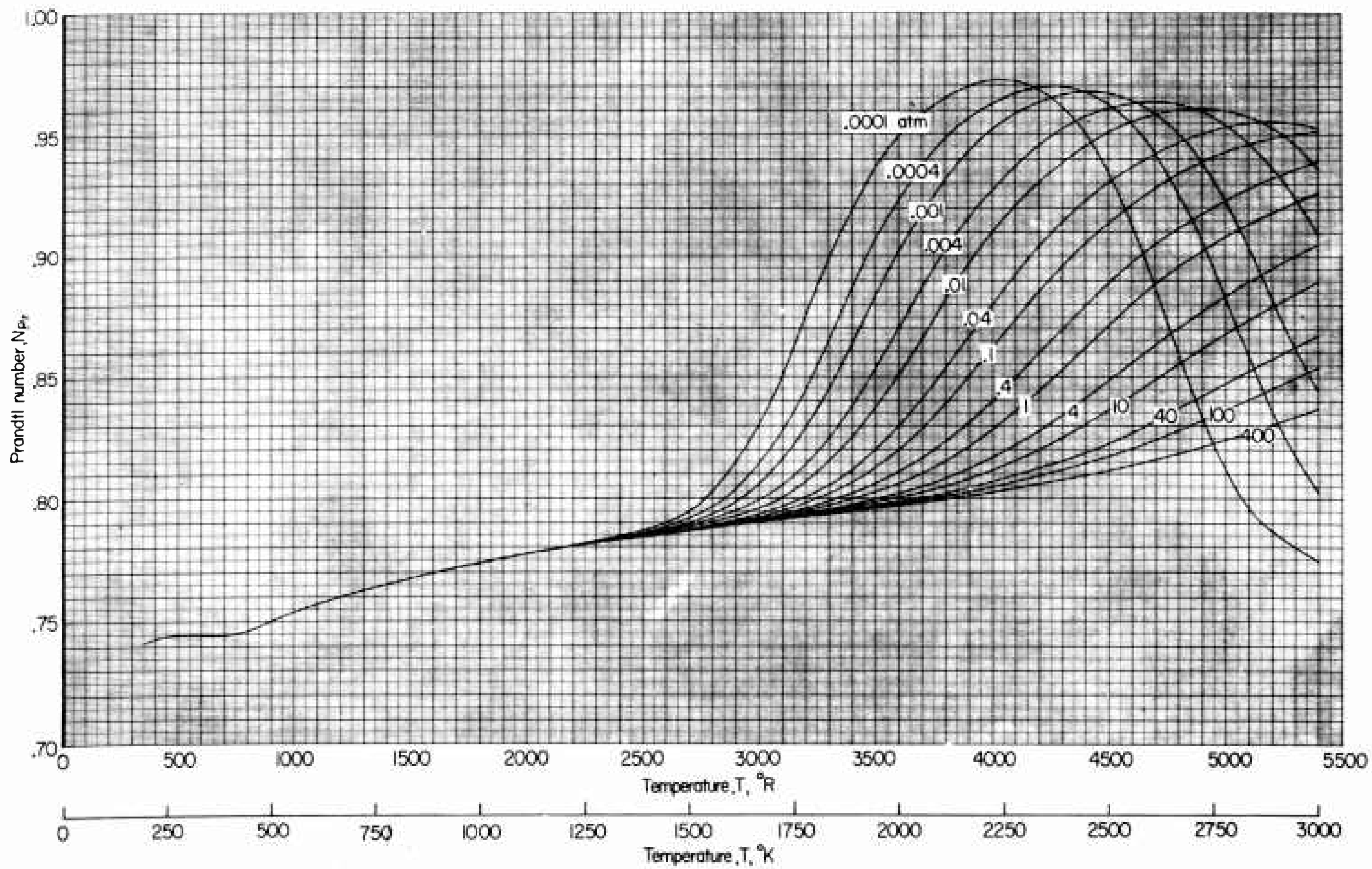
(b) Equivalence ratio, 0.9.

Figure 18.- Continued.



(c) Equivalence ratio, 0.8.

Figure 18.- Continued.



(d) Equivalence ratio, 0.7.

Figure 18.- Concluded.

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50. (NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50. (NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50. (NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50. (NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to 3,000° K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to 3,000° K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to 3,000° K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to 3,000° K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50.
(NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50.
(NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50.
(NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914
National Aeronautics and Space Administration.
CALCULATION PROCEDURE FOR THERMODYNAMIC, TRANSPORT, AND FLOW PROPERTIES OF THE COMBUSTION PRODUCTS OF A HYDROCARBON FUEL MIXTURE BURNED IN AIR WITH RESULTS FOR ETHYLENE-AIR AND METHANE-AIR MIXTURES. E. W. Leyhe and R. R. Howell. January 1962. 103p. OTS price, $2.50.
(NASA TECHNICAL NOTE D-914)

A procedure is presented whereby the composition, thermodynamic properties, and transport properties of the dissociated combustion products of a fuel consisting of a mixed hydrocarbon compound burned in air may be calculated. Equations and procedures for determining supersonic nozzle ordinates and flow properties for the dissociated combustion products are presented in an appendix. Results are presented for the respective hydrocarbon fuels, methane and ethylene, at the equivalence ratios of 1.0, 0.9, 0.8,

Copies obtainable from NASA, Washington (over)

I. Leyhe, Edward W.
II. Howell, Robert R.
III. NASA TN D-914

(Initial NASA distribution: 15, Chemistry, physical; 20, Fluid mechanics; 38, Propulsion systems, air-jet; 44, Propulsion systems, theory.)

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to $3,000^\circ$ K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to $3,000^\circ$ K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to $3,000^\circ$ K.

Copies obtainable from NASA, Washington

NASA

NASA TN D-914

and 0.7 for pressures varying between 10^{-4} and 8×10^2 atmospheres and temperatures from 200° K to $3,000^\circ$ K.

Copies obtainable from NASA, Washington

NASA

UNCLASSIFIED

UNCLASSIFIED